# Status of Mu2e: FNAL PAC 7 June 2013


R. Bernstein

# Mu2e Collaboration

*Boston University*
*Brookhaven National Laboratory*
*University of California, Berkeley*
*University of California, Irvine*
*California Institute of Technology*
*City University of New York*
*Duke University*
*Fermilab*
*University of Houston*
*University of Illinois, Urbana-Champaign*
*University of Massachusetts, Amherst*
*Lawrence Berkeley National Laboratory*
*Northern Illinois University*
*Northwestern University*
*Pacific Northwest National Laboratory*
*Rice University*
*University of Virginia*
*University of Washington, Seattle*

*Istituto G. Marconi Roma*
*Laboratori Nazionale di Frascati*
*Università di Pisa, Pisa*
*INFN Lecce and Università del Salento*
*Gruppo Collegato di Udine*

*Institute for Nuclear Research, Moscow, Russia*
*JINR, Dubna, Russia*

~137 collaborators

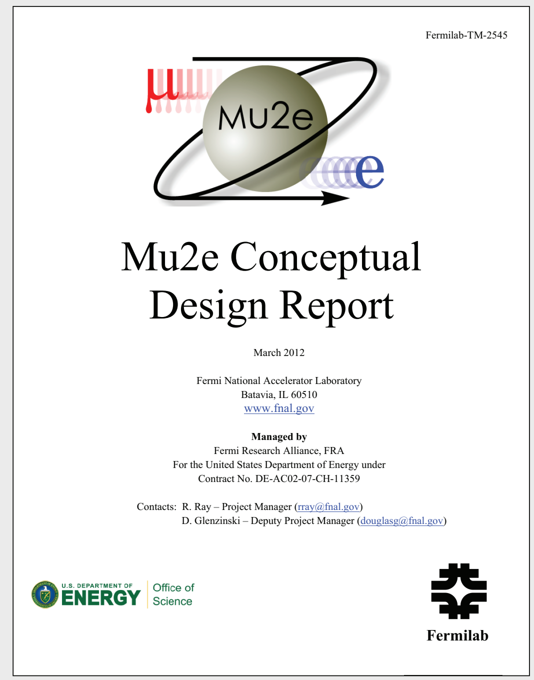
# Overall Message

- Steady progress and working on problems
  - We have chosen a specific tracker, extinction monitor scheme, and calorimeter
  - Are actively prototyping tracker elements
  - Are studying issues from neutrons
- Software/Simulations continue to become more sophisticated and the Collaboration is becoming more expert in its use
- We are moving from “Conceptual Design”, CD-1, cost-range to “Technical Design”, CD-2, and a baselined cost and schedule

# Emphasis

- This Progress Report will be more about physics and detector and software
  - Project is extensively reviewed
  - Only have 35 min
- Will Tell You About Physics Issues
- Will Cover Solenoids/Accelerator in less detail

details: Conceptual Design Report:
arXiv:1211.7019



Fermilab-TM-2545

Mu2e Conceptual Design Report

March 2012

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U.S. DEPARTMENT OF ENERGY | Office of Science

Fermilab

# Outline

- Physics Case and Overview of Experiment
- Software/Simulation Status
- Experiment Design Updates
- Solenoid Status
- Accelerator Status
- Issues
- Summary and Conclusions

# Muon-to-Electron Conversion

muon converts to electron in the field of a nucleus

$$\mu^- N \to e^- N$$

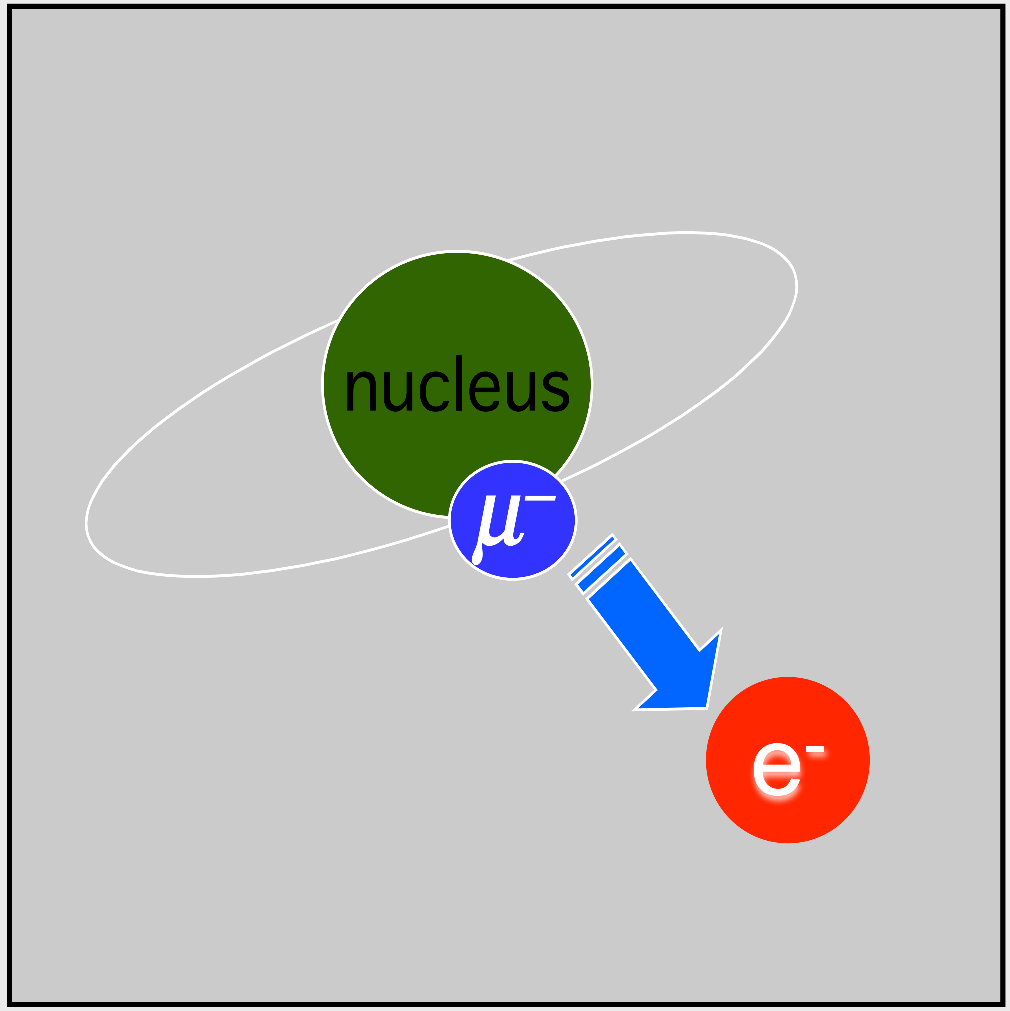
$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z) \to e^- + N(A,Z))}{\Gamma(\mu^- + N(A,Z) \to \text{all muon captures})}$$

- Charged Lepton Flavor Violation (CLFV)
  - manifest Beyond-Standard-Model physics
  - SES of $2.3 \times 10^{-17}$, 0.4 evt bkg; $6 \times 10^{-17}$ at 90% CL
  - Standard Model Background of $10^{-54}$

# Experimental Signal

$$\mu^- N \rightarrow e^- N$$

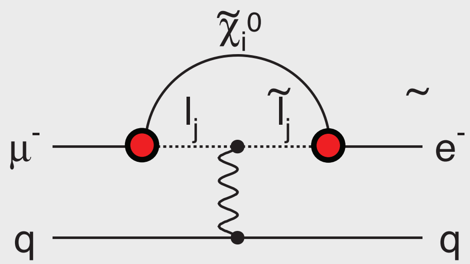
- A Single Monoenergetic Electron
- Energy depends on nucleus
- If $N$ = Al, $E_e$ = 105. MeV
- Nucleus coherently recoils off outgoing electron:
  - two-body process



# Contributions to μe Conversion

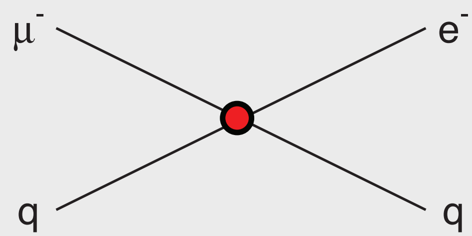
## Supersymmetry

rate ~ $10^{-15}$



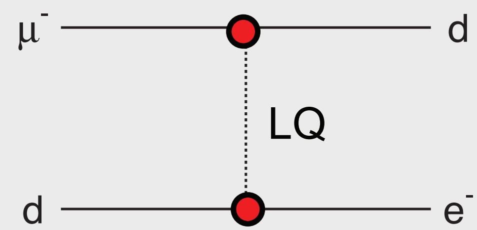

## Compositeness

$\Lambda_c$ ~ 3000 TeV



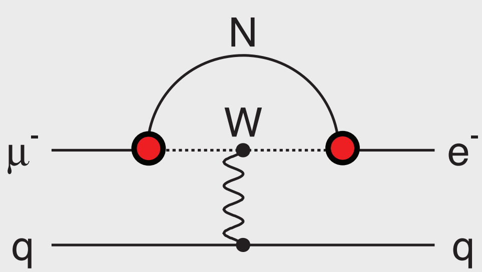

## Leptoquark

$M_{LQ}$ =
3000 $(\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/$c^2$



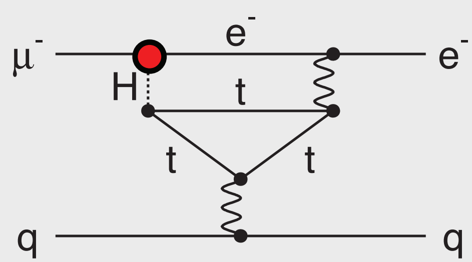

## Heavy Neutrinos

$|U_{\mu N}U_{eN}|^2$ ~ $8\text{x}10^{-13}$



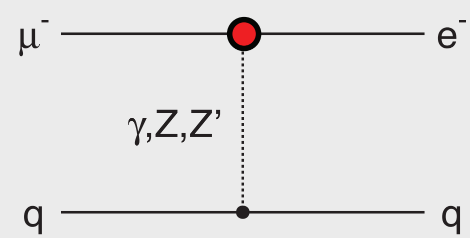

## Second Higgs Doublet

$g(H_{\mu e})$ ~ $10^{-4}g(H_{\mu\mu})$




## Heavy Z' Anomal. Z Coupling

$M_{Z'}$ = 3000 TeV/$c^2$



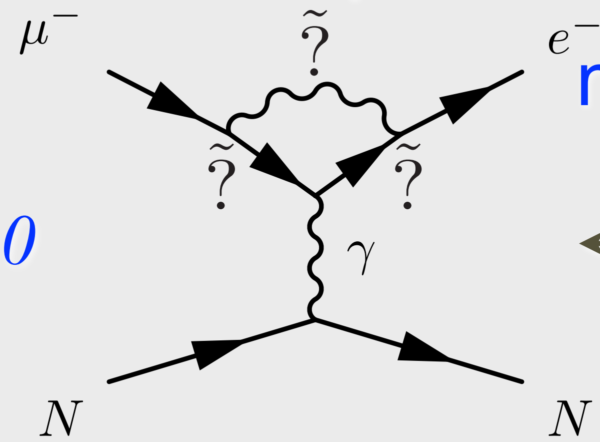

also see Flavour physics of leptons and dipole moments, arXiv:0801.1826 ;
Marciano, Mori, and Roney, Ann. Rev. Nucl. Sci. 58, doi:10.1146/annurev.nucl.58.110707.171126 ;

# “Model-Independent” Form

$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \quad \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{u}_L\gamma_\mu u_L + \bar{d}_L\gamma_\mu d_L)$$

**“Loops”**

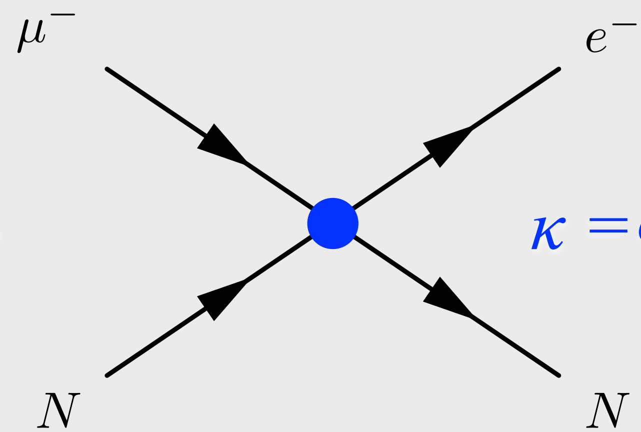
$\kappa = 0$




mass scale $\Lambda$

$\kappa$

**“Contact Terms”**




$\kappa = \infty$

Supersymmetry and Heavy Neutrinos

Contributes to μ→eγ

(imagine the photon is real)

New Particles at High Mass Scale (leptoquarks, heavy Z,...)

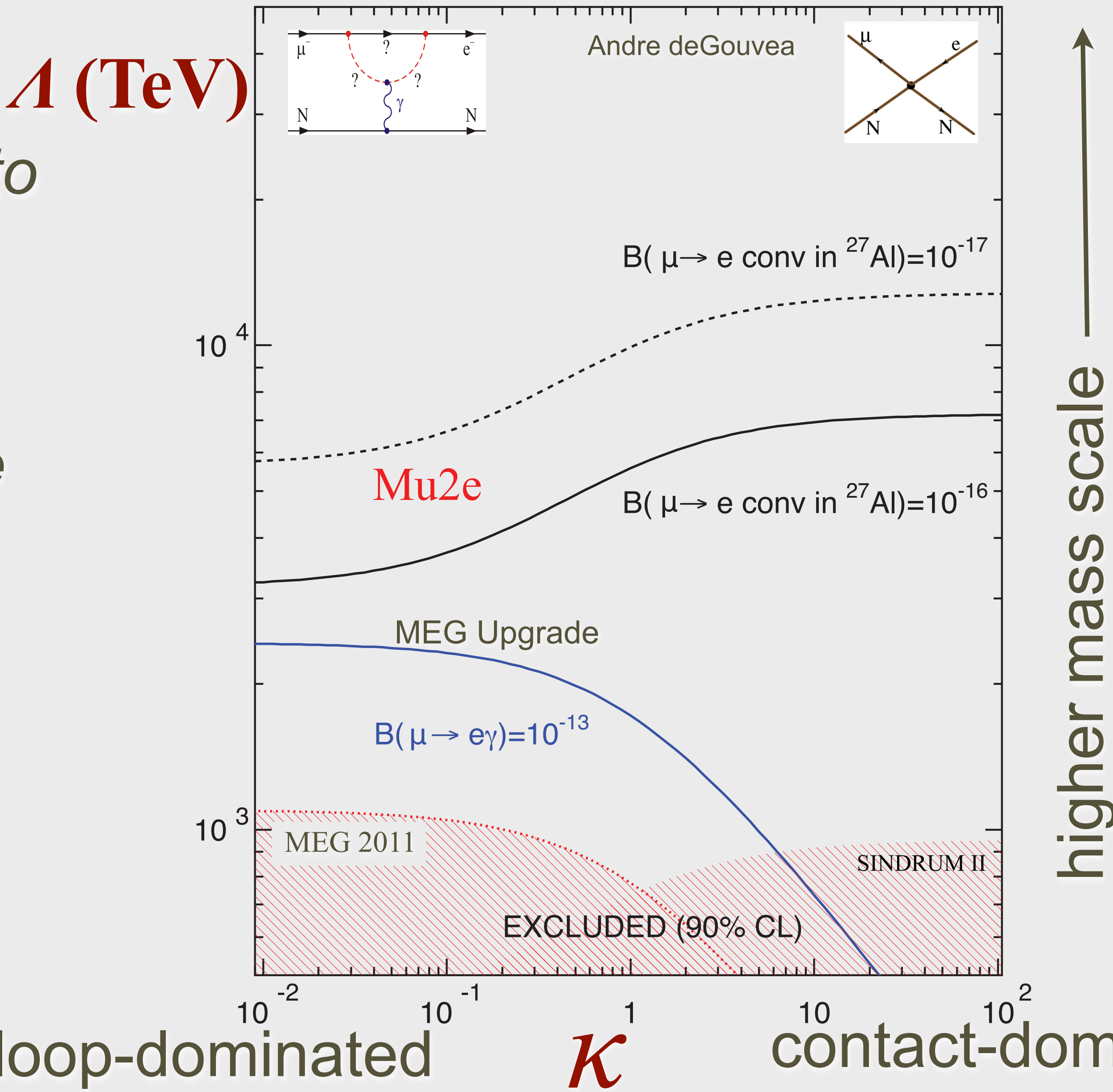
Does not produce μ→eγ

# μe Conversion and μ→eγ

1) *Mass Reach to ~$10^4$ TeV*

2) *roughly equal to MEG upgrade (6e-14) in loop-dominated physics*

3) *Mu2e is a discovery experiment*



# Summary of Physics Case

- Discovery and Discrimination:
  - Mu2e can discover a wide range of physics
    - SUSY, heavy neutrinos, leptoquarks, extended Higgs sectors,...
  - Mu2e can discriminate among models
    - Crudely, the Lagrangian has a numerator (coupling) and denominator (mass scale). A single measurement gets the ratio; using measurements in different CLFV processes and/or varying Z determines both

see talks at 1st Int Conf on CLFV: http://clfv2013.le.infn.it

# Mu2e And the LHC

New Physics at LHC?

yes

Mu2e Signal?

yes

1) arXiv implodes
2) models have to explain the signal
3) Project X

no

1) Null Result has enormous discriminating power for models explaining LHC result
2) Project X

no

Mu2e could see a signal from physics up to $10^4$ TeV

# Evolution of Program

- Exploration With $Z$ is vital; Mu2e upgrades and higher $Z$ under study

*V. Cirigliano, R. Kitano, Y. Okada, P. Tuzon., arXiv:0904.0957 [hep-ph]; Phys.Rev. D80 (2009) 013002*

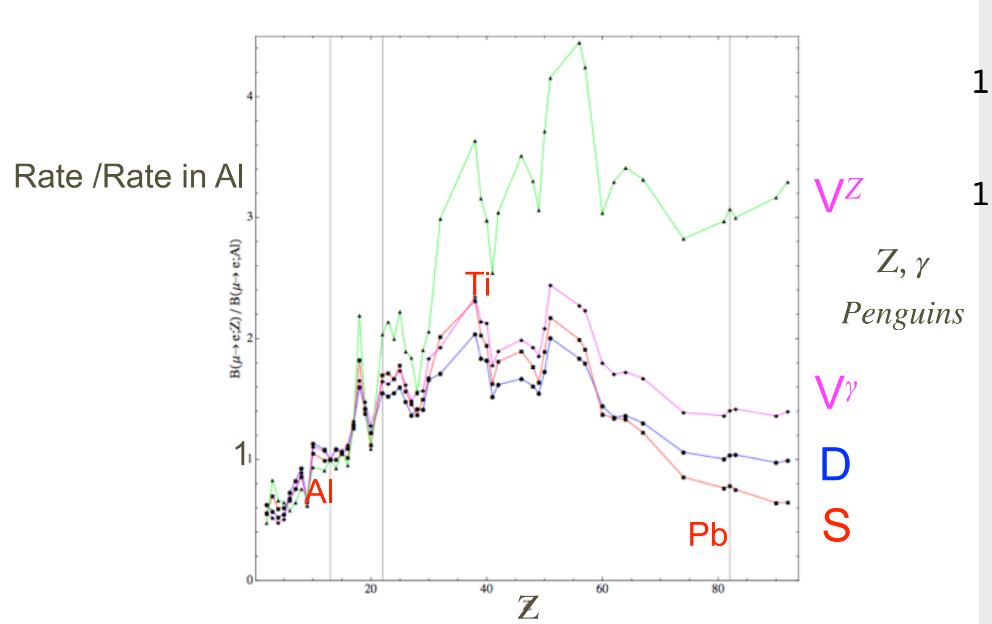
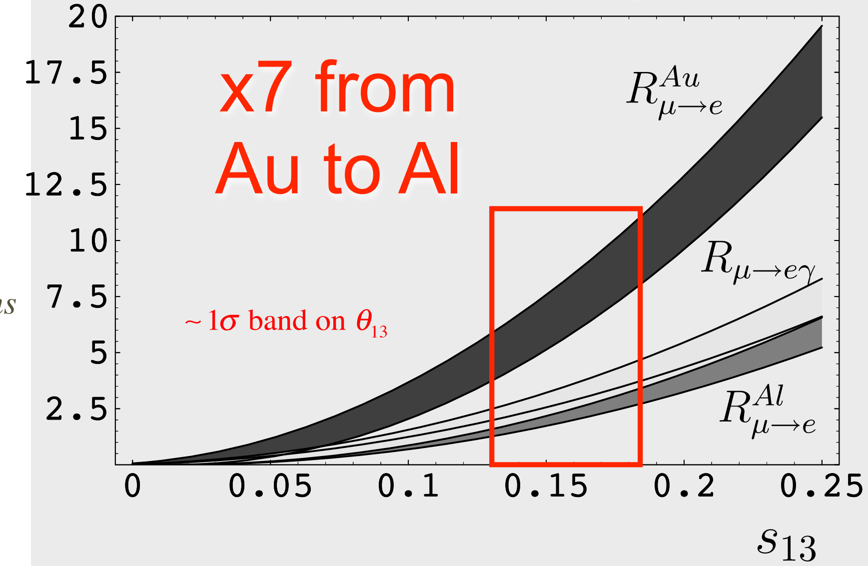



Figure 3: Target dependence of the $\mu \to e$ conversion rate in different single-operator dominance models. We plot the conversion rates normalized to the rate in Aluminum ($Z = 13$) versus the atomic number $Z$ for the four theoretical models described in the text: $D$ (blue), $S$ (red), $V^{(\gamma)}$ (magenta), $V^{(Z)}$ (green). The vertical lines correspond to $Z = 13$ (Al), $Z = 22$ (Ti), and $Z = 83$ (Pb).

*$\theta_{13}$: G. Fogli et al., arXiv:1205.5254*




V. Cirigliano, B. Grinstein, G. Isidori, M. Wise
**Nucl.Phys.B728:121-134,2005**

# Unsolicited Testimonial

- From Sheldon Glashow, 5/23/2013: (italics mine)

Particle Physics in The United States

A Personal View
Sheldon Lee Glashow
Boston University

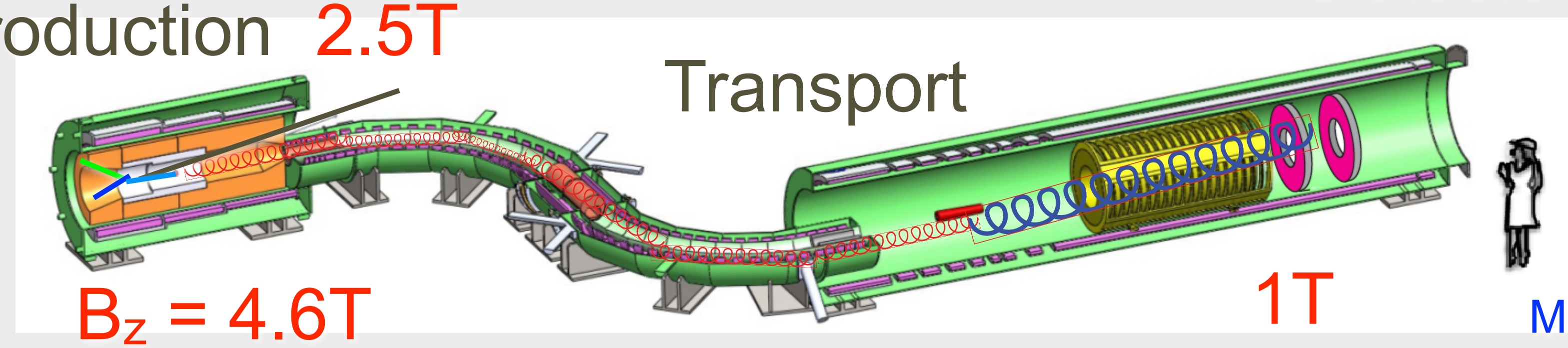
Testing Flavor Symmetries with Muons:

I focus on these three changing muon decay modes: radiative decay ( $\mu \to e + \gamma$ ), 3-e decay, ($\mu \to e + e + e$) and orbital conversion ($\mu + N \to e + N$) ... Because their standard-model branching ratios are far too tiny for possible detection, observation of any mode would be certain evidence of new physics. *That's what makes such sensitive searches potentially transformative.*

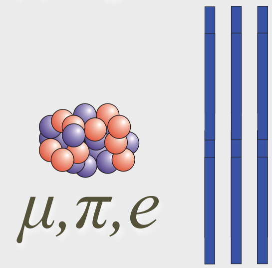
http://arxiv.org/abs/arXiv:1305.5482

# Mu2e Muon Beam: Three Solenoids and Gradient

4.6T ⟶ B-field gradient ⟶ 1T

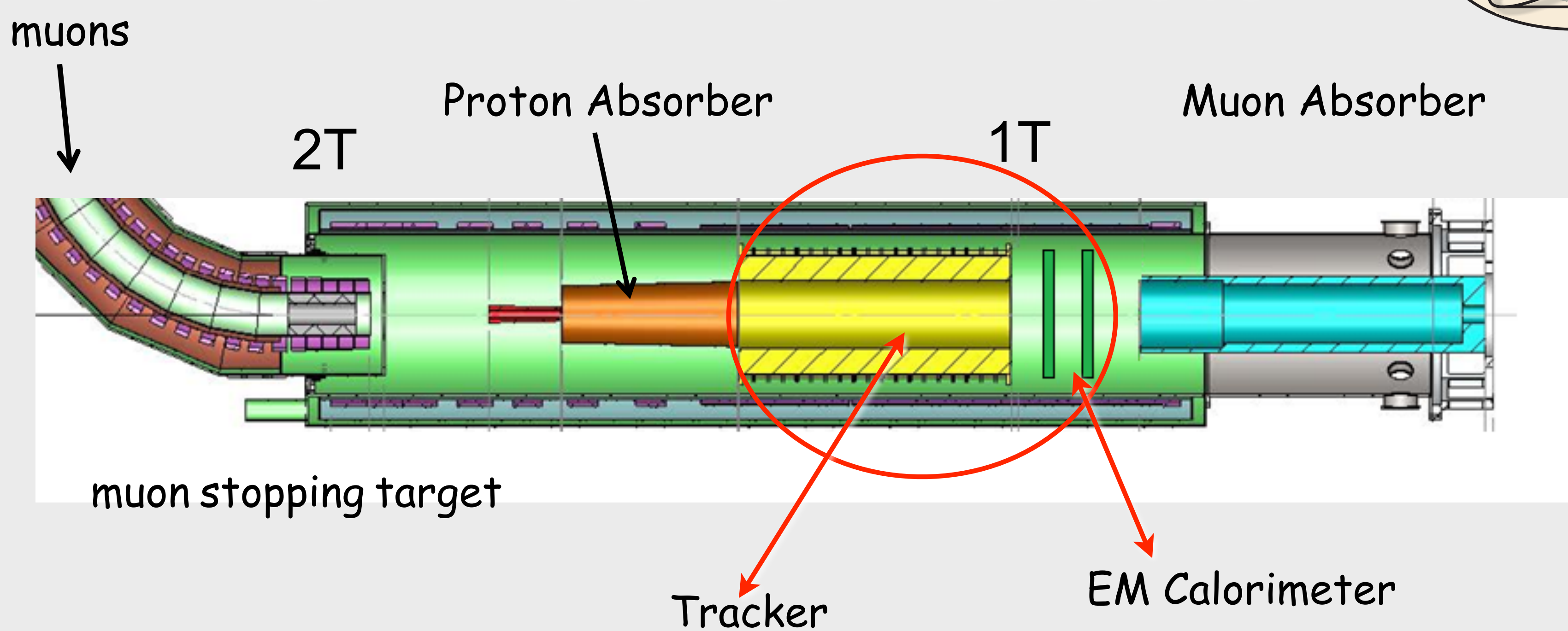



Muon Momentum ~ 50 MeV/c: muons range out in stopping foils




- Target protons at 8 GeV inside superconducting solenoid
- Capture muons and guide through S-shaped region to Al stopping target
- Gradient fields used to collect and transport muons

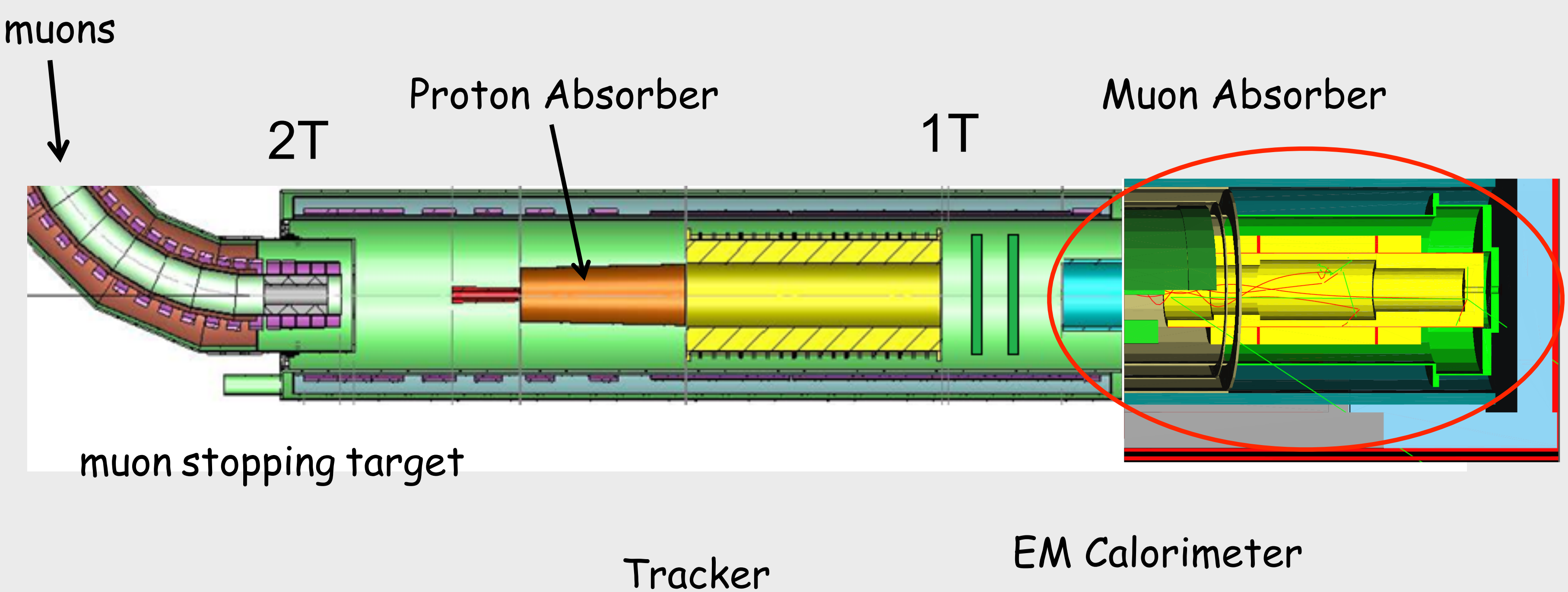
# Reminder of Detector




- Tracker technology downselect: were considering a drift chamber but decided to stay with straws; drift chamber will be used for MEG upgrade

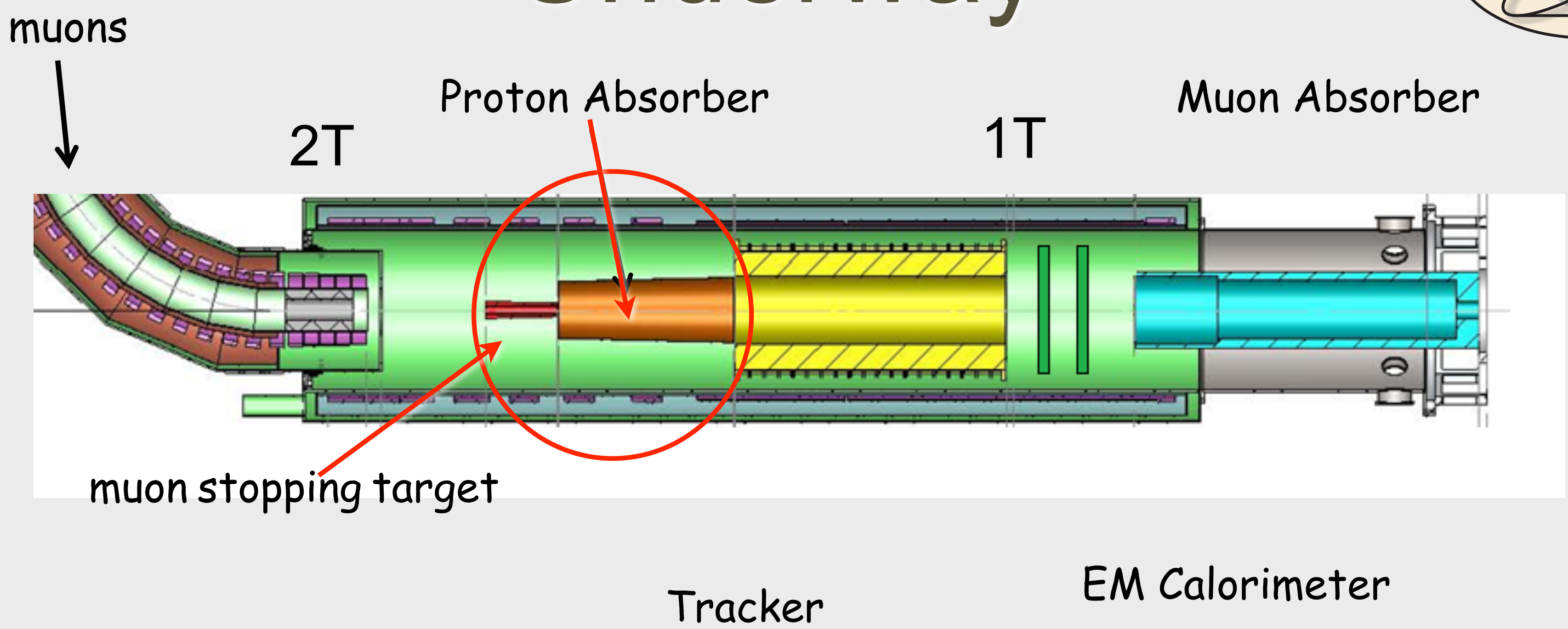
- Big change in calorimeter: went from four vanes oriented along beamline to two disks.

# Reminder of Detector



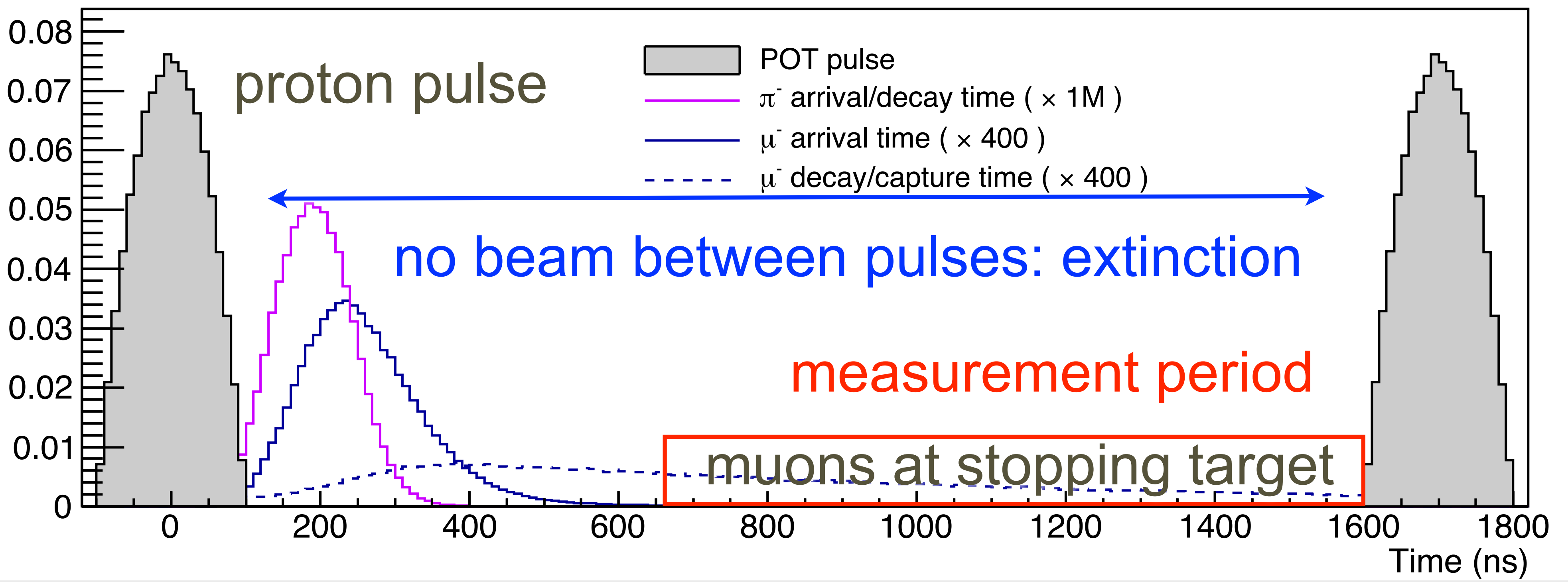

- First real, careful design of beam stop by NIU and FNAL. Must minimize albedo back into detector
- I will skip this today for lack of time

# Underway




- Muon capture process ejects protons, neutrons and photons
  - protons have large *dE/dx* and can deaden detector
- Both the stopping target and absorber are sources of energy loss and scattering that degrade the resolution – these two completely dominate the width of the signal peak, and contribute about equally.
- Optimization, measurements underway: AlCap at PSI

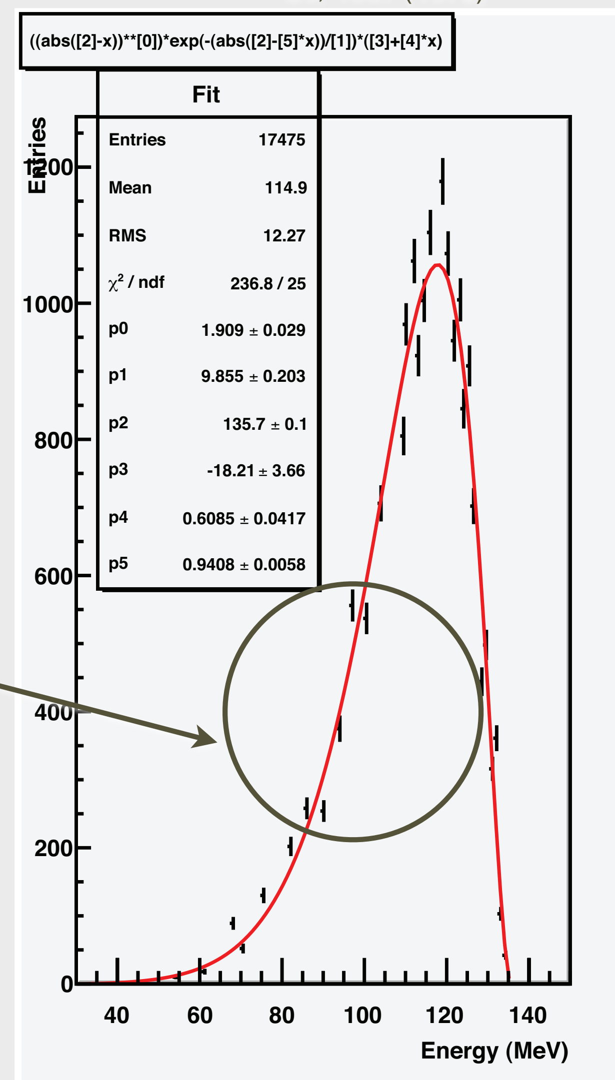
# Beam Time Structure




- Muons reach the stopping target in ~250 ns
  - Stopped muon lifetime on Al ~800 nsec
- Measurement Period after beam flash, prompt bkgs ($\pi^-$) decay
  - ~1 μsec window, ~50% acceptance

# Prompt Backgrounds

energy spectrum of $\gamma$ measured on Mg
J.A. Bistirlich, K.M. Crowe et al., Phys Rev C5, 1867 (1972)

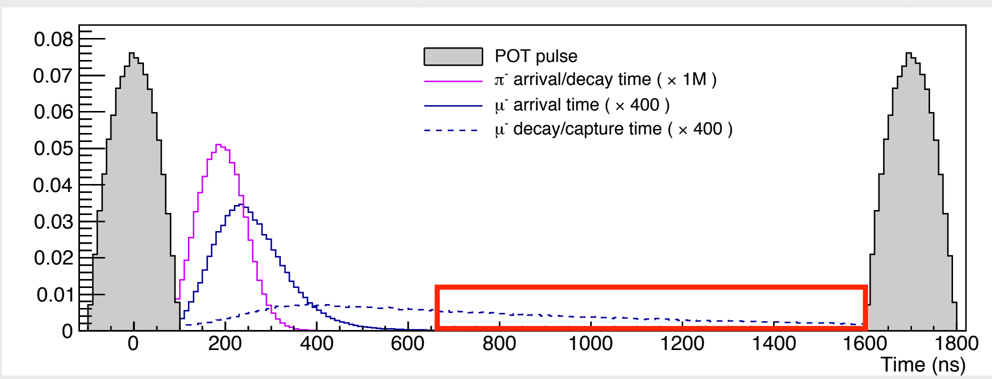



- **Radiative pion capture**, $\pi^- + A(N,Z) \rightarrow \gamma + X$.
    - $\gamma$ up to $m_\pi$, peak at 110 MeV; $\gamma \rightarrow e^+e^-$ ; if one electron ~ 100 MeV in the target, looks like signal: ***limitation in best existing experiment, SINDRUM II?***
    - data of good quality and can estimate errors
    - this is why we wait for measurement period: about $10^{11}$ suppression of RPC

also included internal conversion, $\pi^- N \rightarrow e^+ e^- X$

# Antiproton-Induced RPC

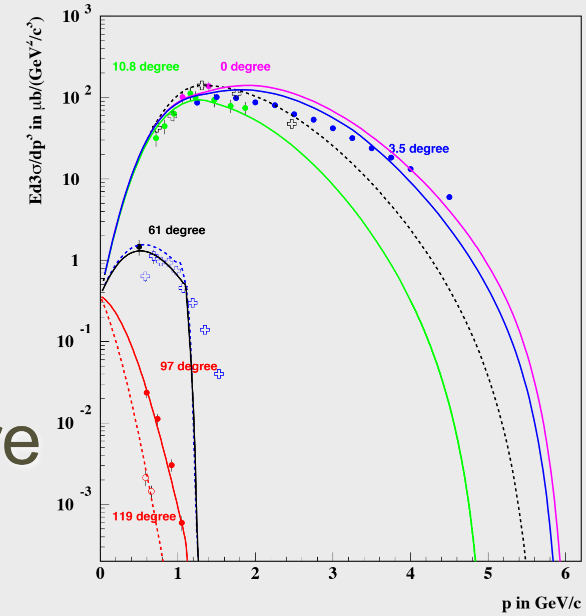
- antiprotons produce RPC background
  - produced in the production target and have low KE, therefore propagate slowly to the stopping target
  - since they are slow, they evade the extinction requirement and the measurement period selection
  - annihilation of antiprotons makes pions




slow antiprotons arrive in measurement period and instantly produce RPCs

# What Do We Need to Know About Pbars?

from S. Striganov, FNAL

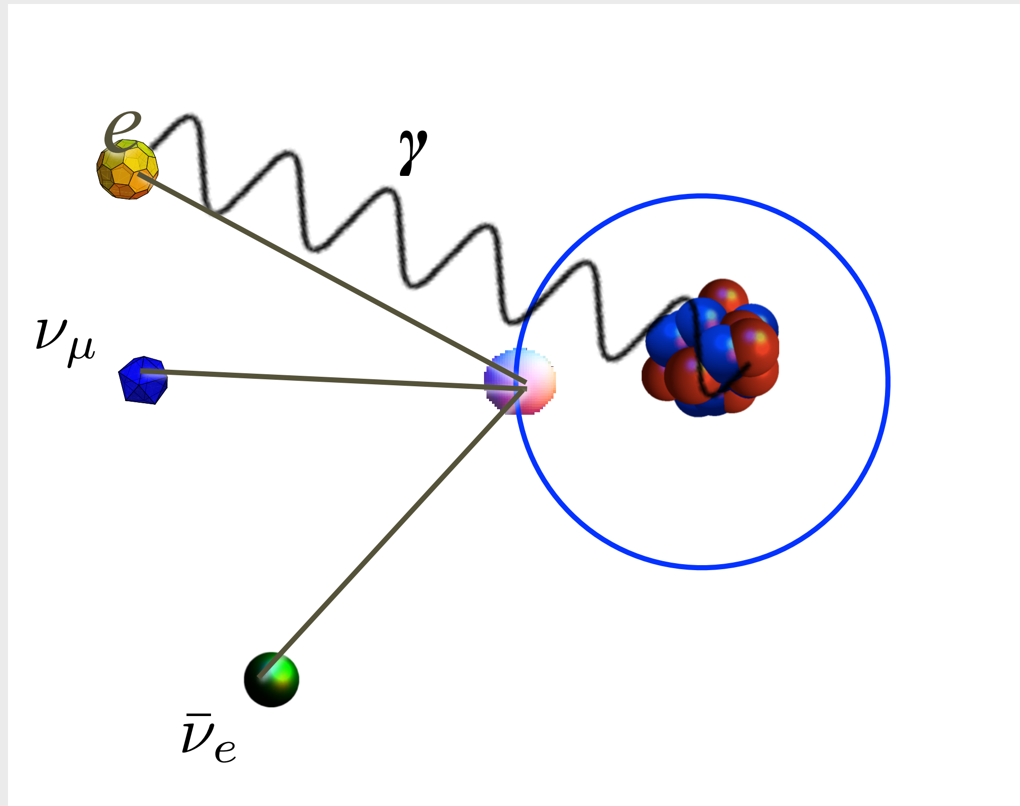


Antiproton production in proton tantalum interaction near 10 GeV/c.

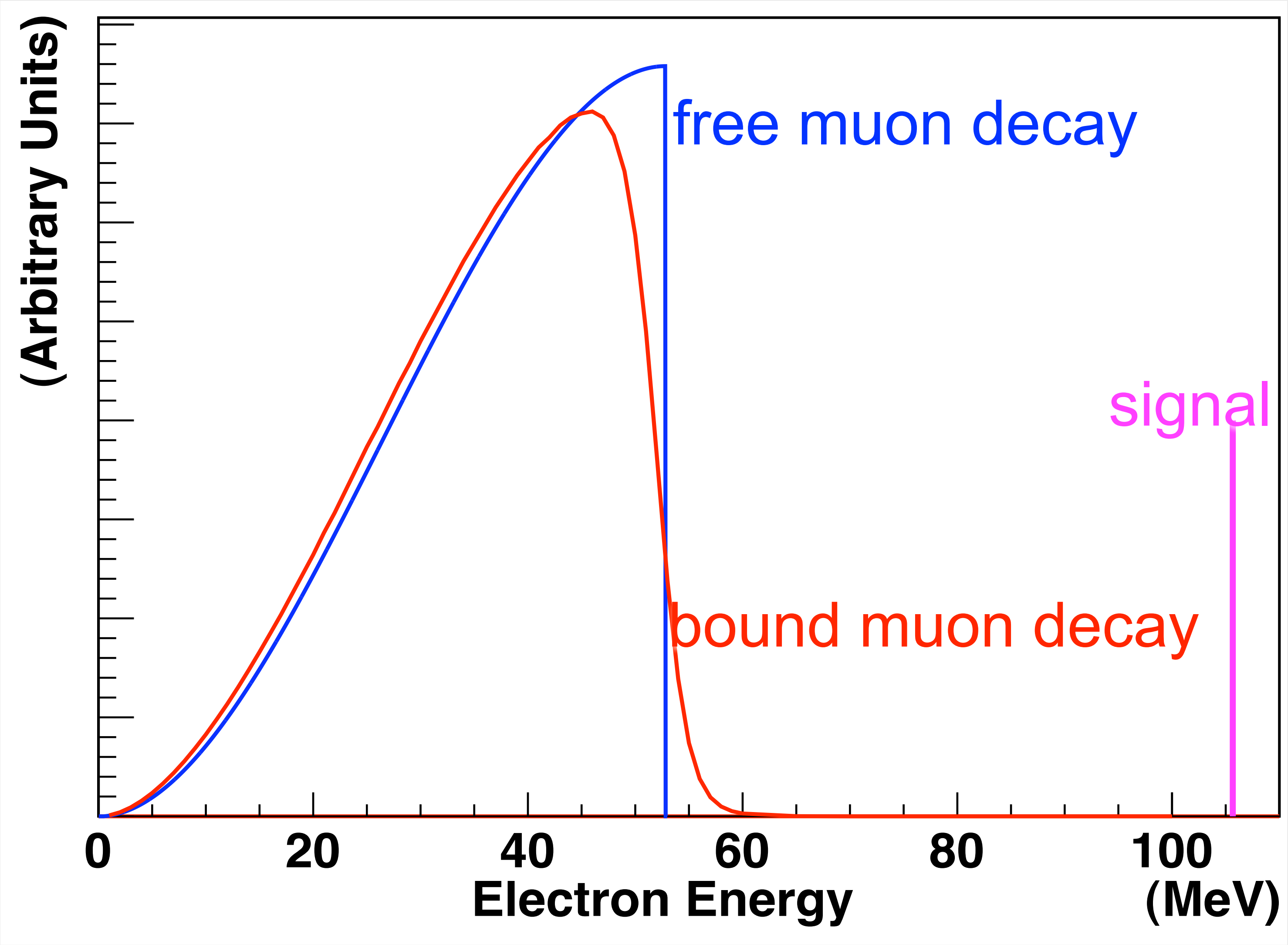
- Differential Cross-Section
- Pions (and other particles) produced in annihilation
- We get these from MARS group and are checking against primary data and G4
- Have designed a window in center of solenoid system to reduce antiprotons to an acceptable level; annihilate far from stopping target
- Design for < 0.02 bkg events, hence large safety margin relative to total 0.4 event bkg

# Instrinsic: Decay-In-Orbit Background

- Electron can recoil off nucleus after normal muon decay
- Imagine jumping to the neutrino zero-momentum frame: looks like an electron recoiling against a nucleus, same as signal
- The DIO electron can be exactly at conversion energy (up to neutrino mass)



# Decay-in-Orbit Spectrum

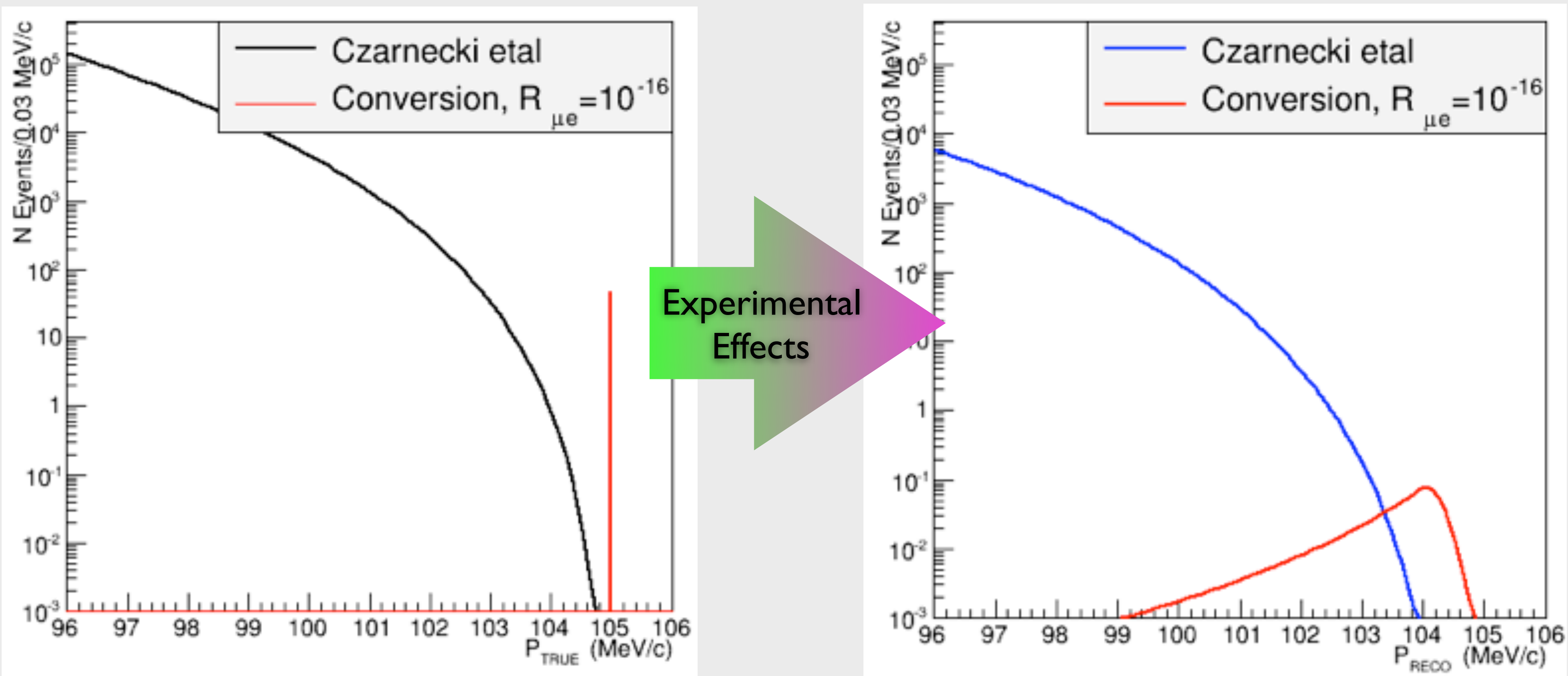


# Spectrum Near Endpoint

Czarnecki, Tormo, Marciano: arXiv:1106.4756 **Phys.Rev. D84 (2011) 013006**

pure theory: $(E_{conv} - E)^5$

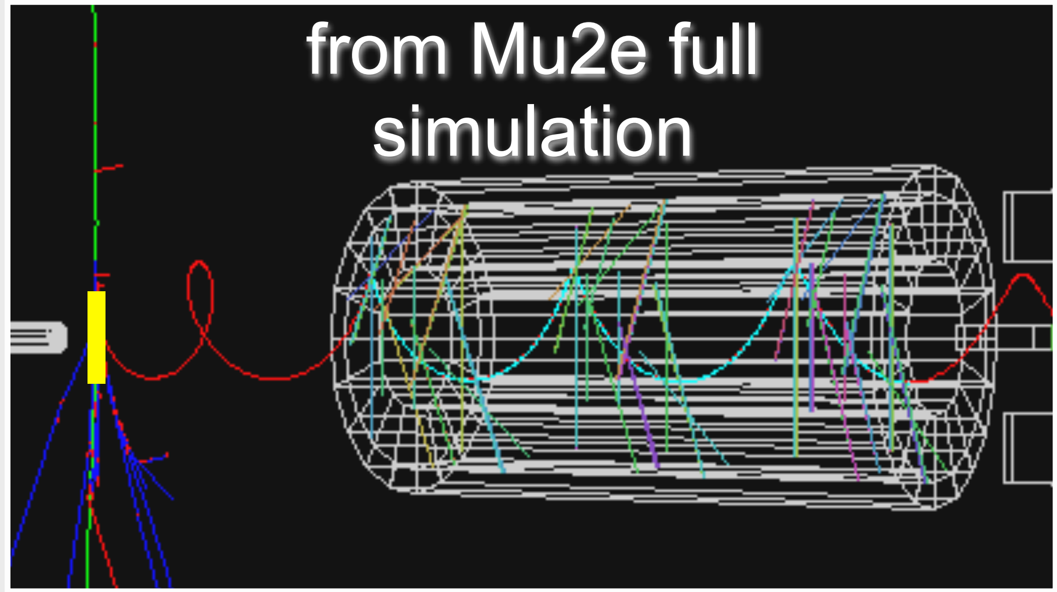
spectra on log scales

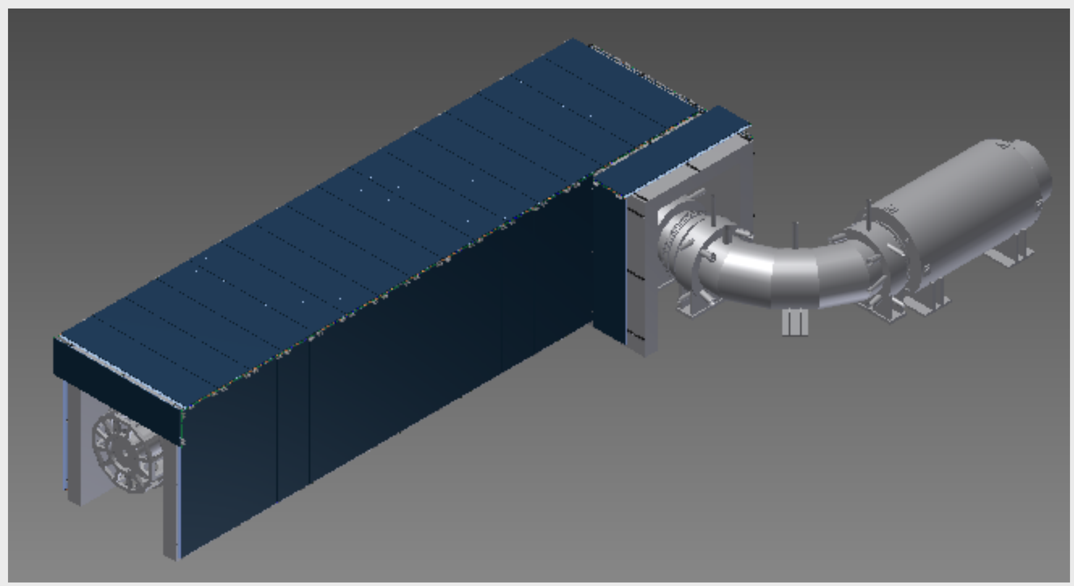



authors are adding radiative corrections to spectrum

# Cosmic Ray Background

- Muons pass through stopping target and knock out electron indistinguishable from signal
- Would be 1/day without CRV
- Issue with CRV's is neutron flux: more later



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# Software/Simulation

- Mu2e has an active core of physicists working on the full (Offline = art/C++/G4) suite, together with input from G4Beamline and MARS
  - use full power of Offline as default:
    - can follow particle history, write out all information,can overlay accidental activity, feeds directly into full reconstruction, plays well on grid
  - model is to do some designs, where easier, in MARS or G4Bl and then move to Offline for official results
  - or use MARS where MARS is best and then combine with Offline

# People Using Full Simulation

| Institution | Last Name | First Name | Position | Role | User/Developer |
|---|---|---|---|---|---|
| BU | Barnes | Emma | Post-Doc | Beamline & Backgrounds | U |
| BU | Logashenko | Vanya | Senior | Beamline & Backgrounds | UD |
| Caltech | Echenard | Bertrand | Post-Doc | Calorimeter | UD |
| Fermilab | Gaponenko | Andrei | Wilson Fellow | Background Coordinator | UD |
| Fermilab | Bernstein | Robert | Co-Spokesperson | Beamline& Backgrounds | UD |
| Fermilab | Knoepfel | Kyle | Post-Doc | Beamline & Backgrounds | UD |
| Fermilab | Kutschke | Rob | Senior | Head of Software | UD |
| Fermilab | Murat | Pavel | Senior | Reconstruction | U |
| Fermilab | Rusu | Vadim | Senior | Detector | UD |
| INFN Lecce | Tassielli | Gianfranco | Post-Doc | Reconstruction | UD |
| INFN Lecce | Ignagtov | Fedor | Senior | Reconstruction | U |
| INFN Lecce | Onorato | Giovanni | Senior | Backgrounds | UD |
| INFN Pisa | Pezzullo | Gianni | PhD Student | Calorimeter | U |
| Irvine | You | Zhengyun | Post-Doc | Extinction | UD |
| NIU | Hodges | Zachary | Student | Stopping Target | U |
| NIU | Yurkewicz | Adam | Post-Doc | Stopping Target | U |
| Rice | Chandra | Avdhesh | Post-Doc | Stopping Target | U |
| UC Berkeley | Brown | David | Senior | Reconstruction | UD |
| UC Berkeley | Lee | Myeongjae | Post-Doc | Reconstruction | UD |
| UVA | Ehrlich | Ralf | Post-Doc | CRV and Event Display | UD |
| York | Lynch | Kevin | Senior | GEANT Physics Lists | UD |

= 21 / 137 collaborators

# G4Beamline/MARS

- Primarily for neutron modeling, Cosmic Ray Veto, and Beam Dump

| Institution | Last Name | First Name | Position | Role |
|---|---|---|---|---|
| BU | Miller | James | Co-Spokesperson | Beamline & Backgrounds |
| BU | Barnes | Emma | Post-Doc | Beamline & Backgrounds |
| Fermilab | Coleman | Rick | Senior | Neutron Modeling |
| Fermilab | Khalatian | Vladimir | Student | Beamline & Backgrounds |
| NIU | Hedin | David | Senior | Muon Beam Dump |
| UVA | Okuzian | Yuri | Post-Doc | CRV |
| UVA | Frank | Martin | Post-Doc | CRV |

take-away: > 28 collaborators actively working on simulations at all levels, most of whom are using FNAL’s art package

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# Major Downselects

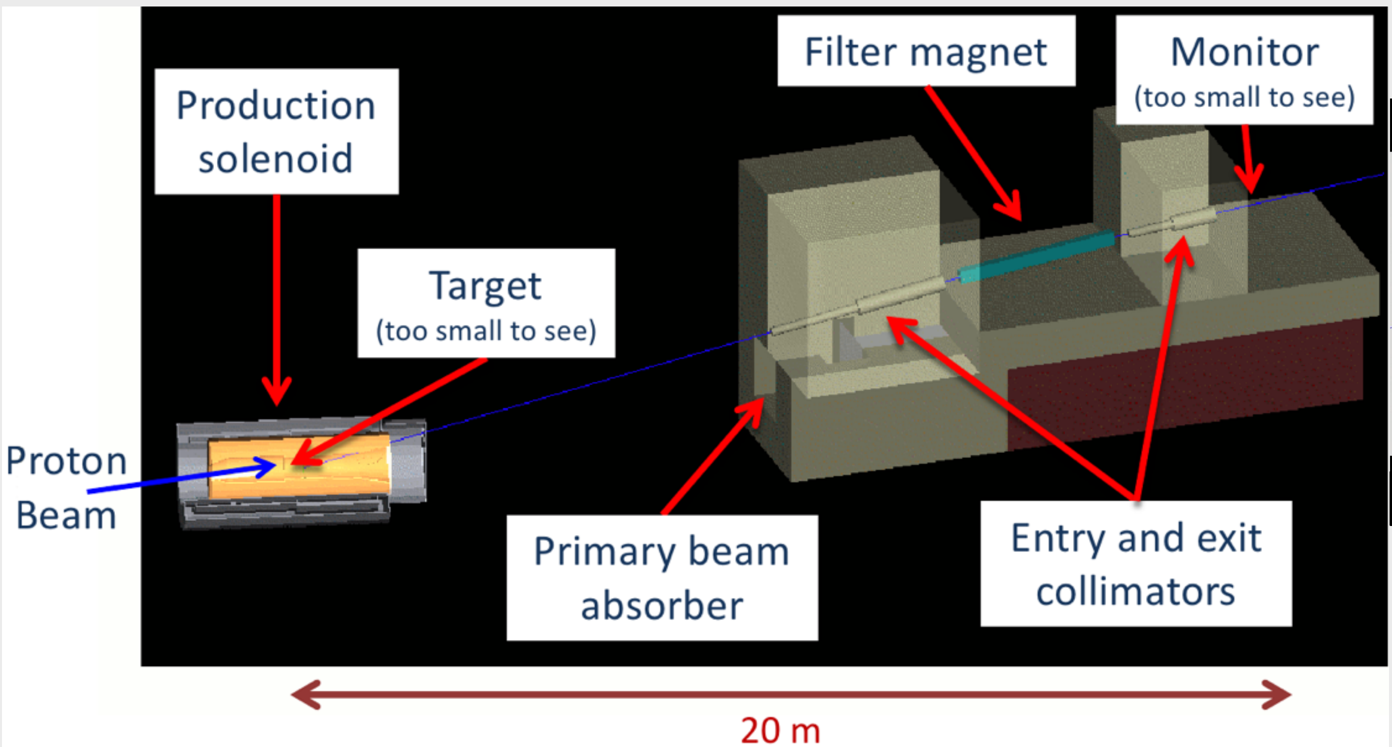
- Extinction Monitoring
- Tracker
- Calorimeter

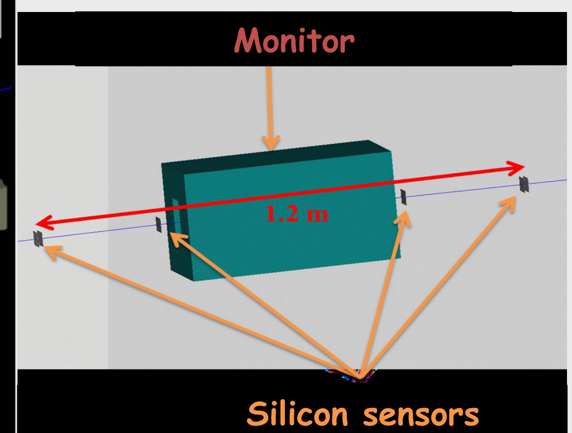
# Extinction Scheme

- Need $10^{-10}$ in-pulse/out-of-pulse protons, and be able to measure in ~ 1 hr
- Direct beam counting not technically feasible and had potentially large systematics
- Dual Telescope:
  - one before extinction dipole: $10^{-(4-5)}$
  - one looking at primary target: $10^{-10}$
- Will also have "diagnostic dump" upstream of solenoids: can establish $10^{-10}$ before data taking and can identify and correct problems

# Extinction Telescope

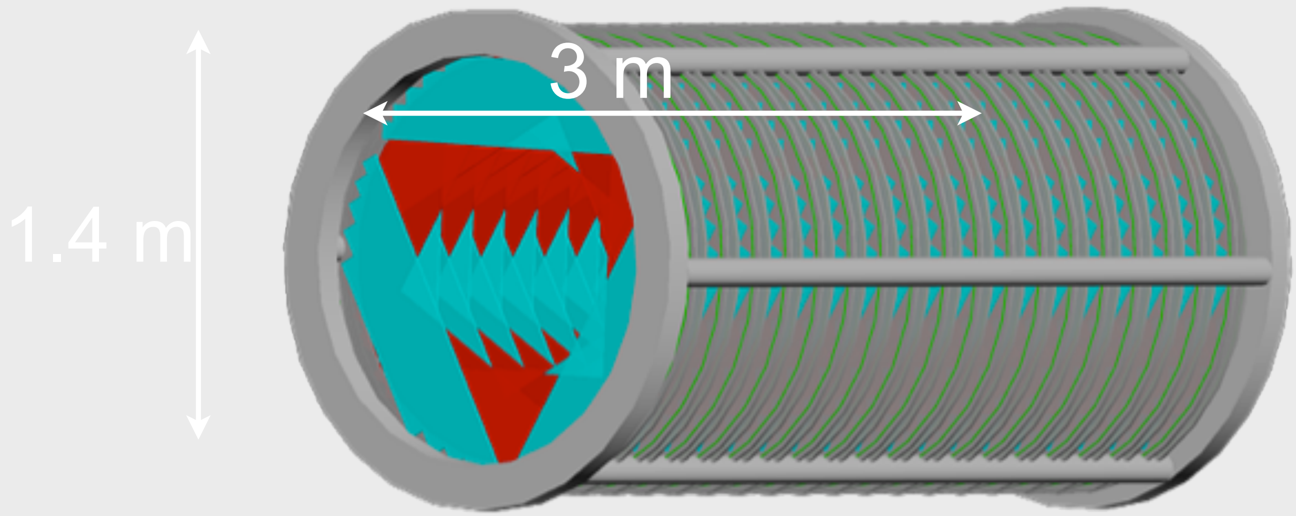
- Si Pixel Telescope (getting help from Purdue with pixel expertise)
- Augmenting with calorimetric PID (Rice)




prototype test
Fall 2013

# Tracker

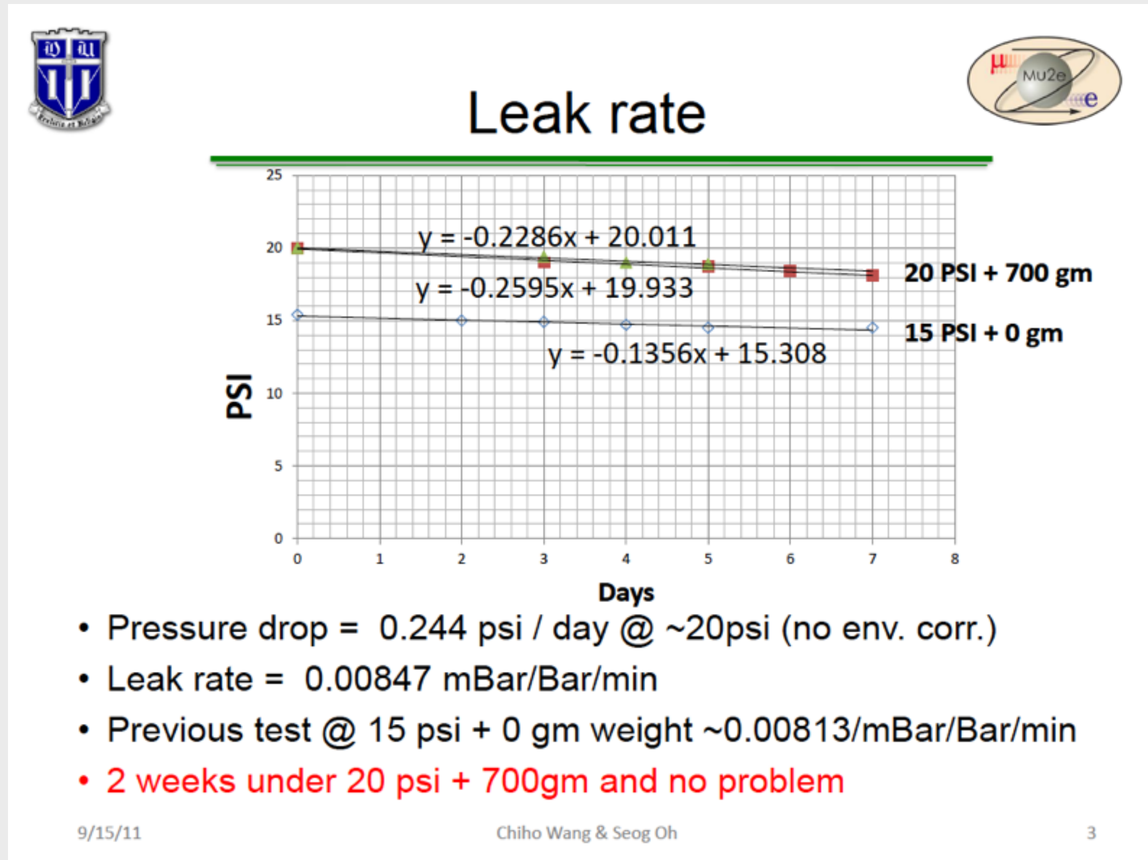



- 18 stations of straw chambers
  - 12 panels of parallel double-layer straws
- 21,600 straws
  - 5 mm diameter, 15 µm mylar walls
- Custom ASIC for Time Division readout
  - < 50 psec $\Delta t$ resolution

# Prototyping Tracker

Sixteen Straws here,"panel" test in fall

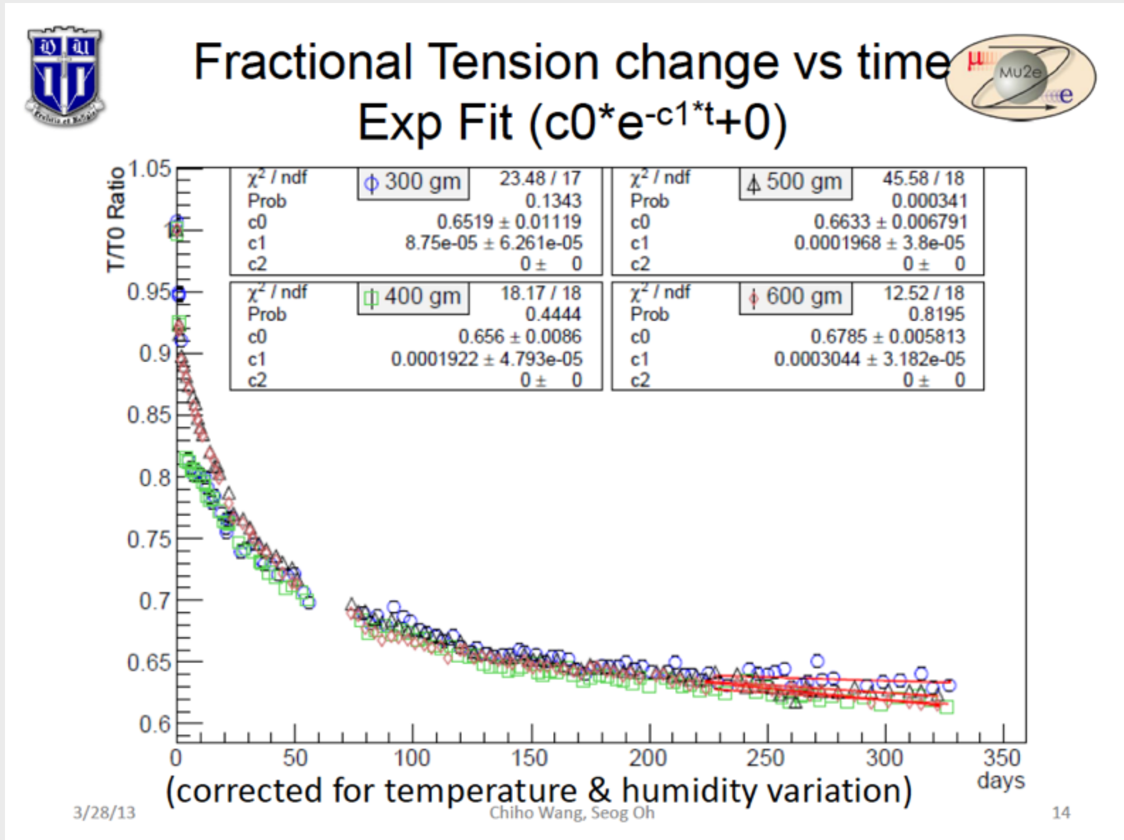
- 15 micron straws in vacuum is not trivial
- We are studying sag, creep, leak
- leak rate < 2 ccm, require < 7 ccm




do straws leak?

# Prototyping Tracker

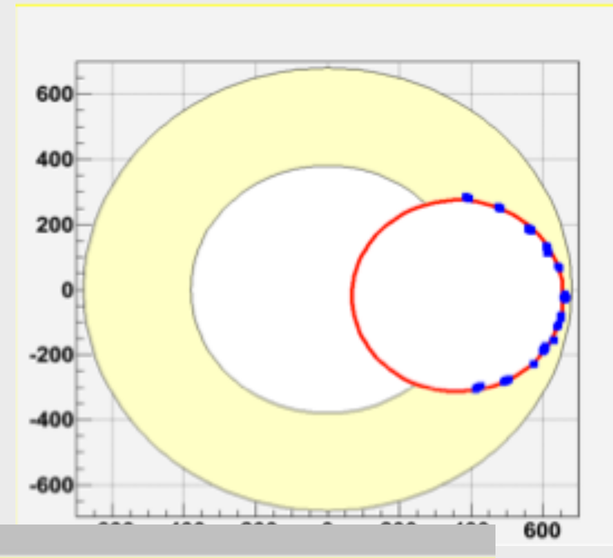
- Do straws creep, i.e. lose tension?
- Creep measured, good for ≥ 7 years

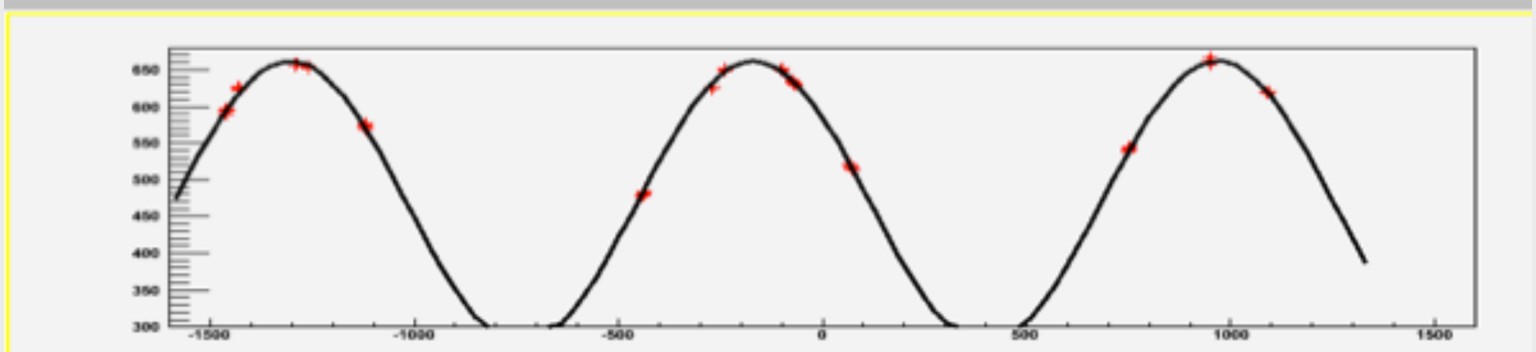



tension over 325 days: relaxes to constant

# Pattern Recognition

this is what a helical conversion track looks like in a toy MC: circle in end-view, sine-wave from side

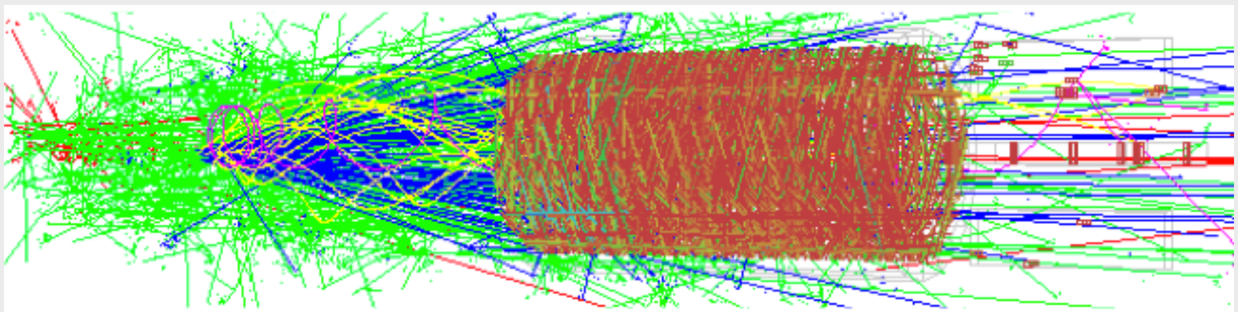


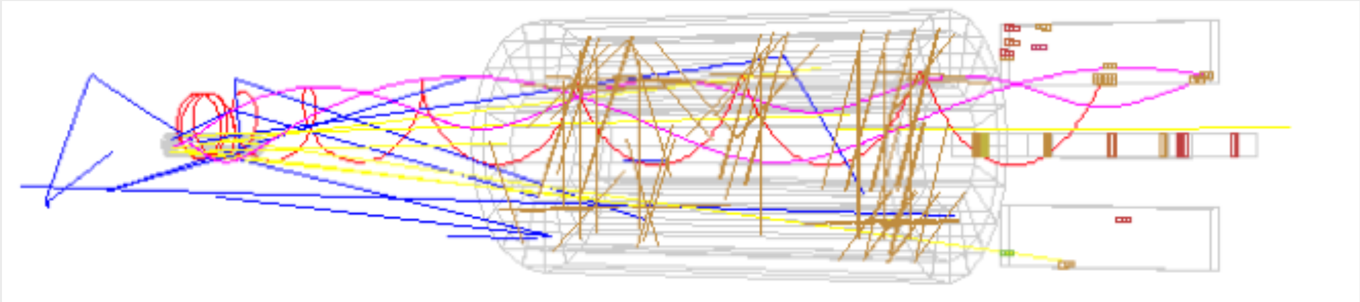

- Learned from Simulations We Need More Information

# Back to Simulations

- Single Proton Pulse: hits in 500-1695 sec window, all of this in simulation



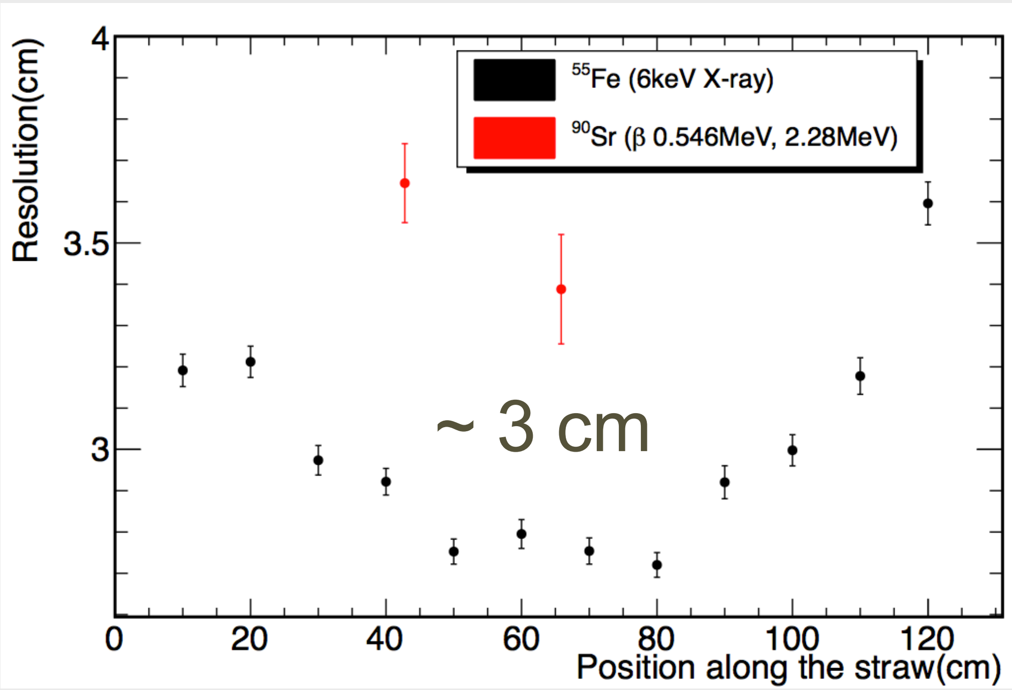
- first step: get time information from tracker , ± 50 nsec:

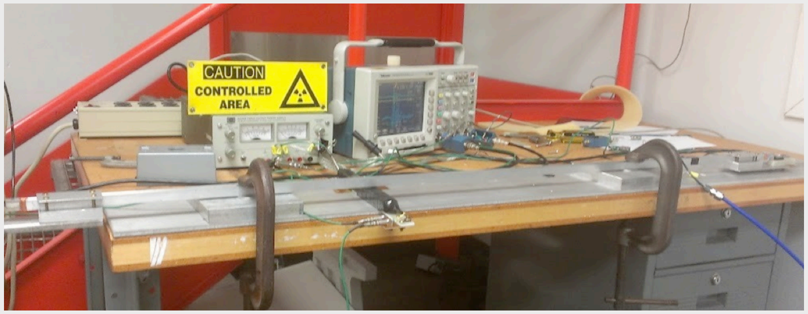


- want better, get position along straw: 3rd coordinate by time-division

# 3rd Coordinate Readout

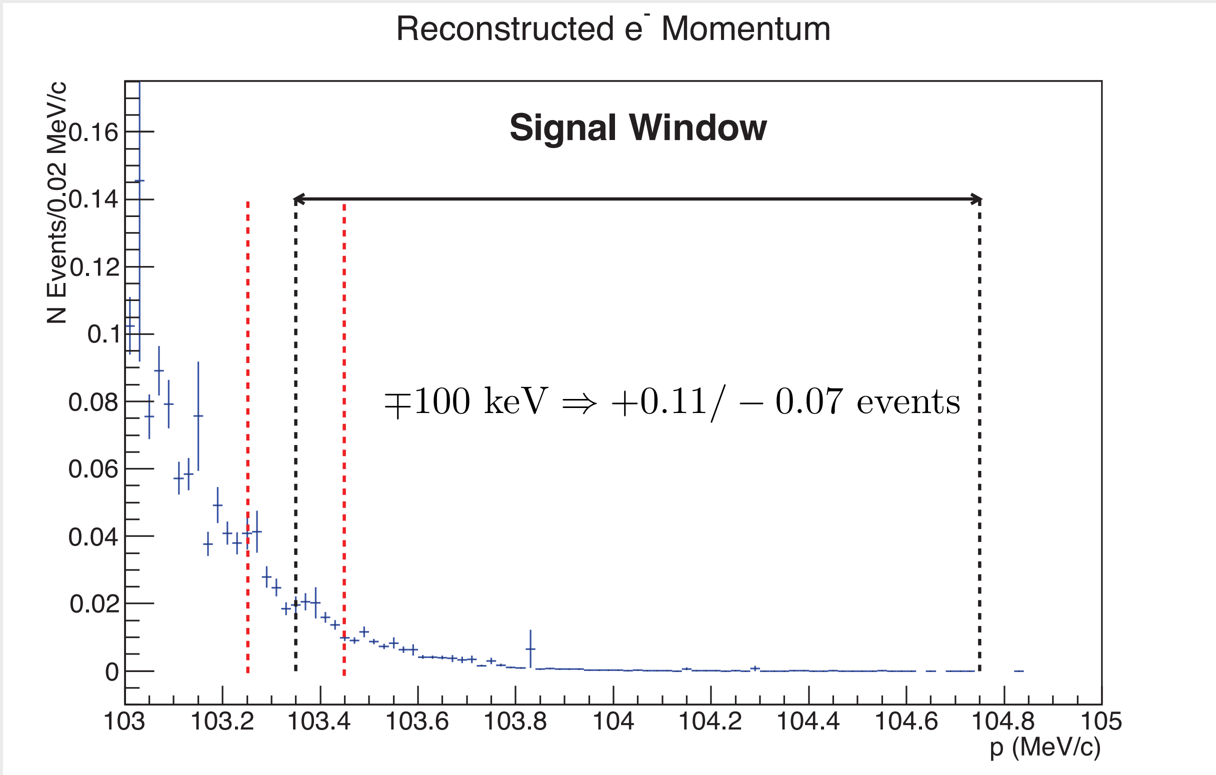
- Use Time Division
- *MEASURED* resolutions used in simulations



# Tracker Momentum Scale

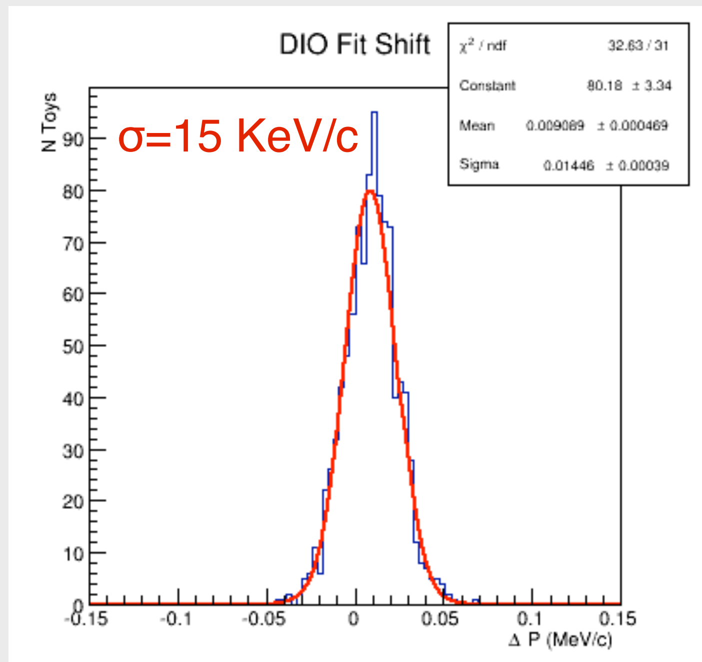
- Suppose we're setting a limit, so no signal
- a scale shift then moves DIO into or out of signal window



# Momentum Scale Determinination

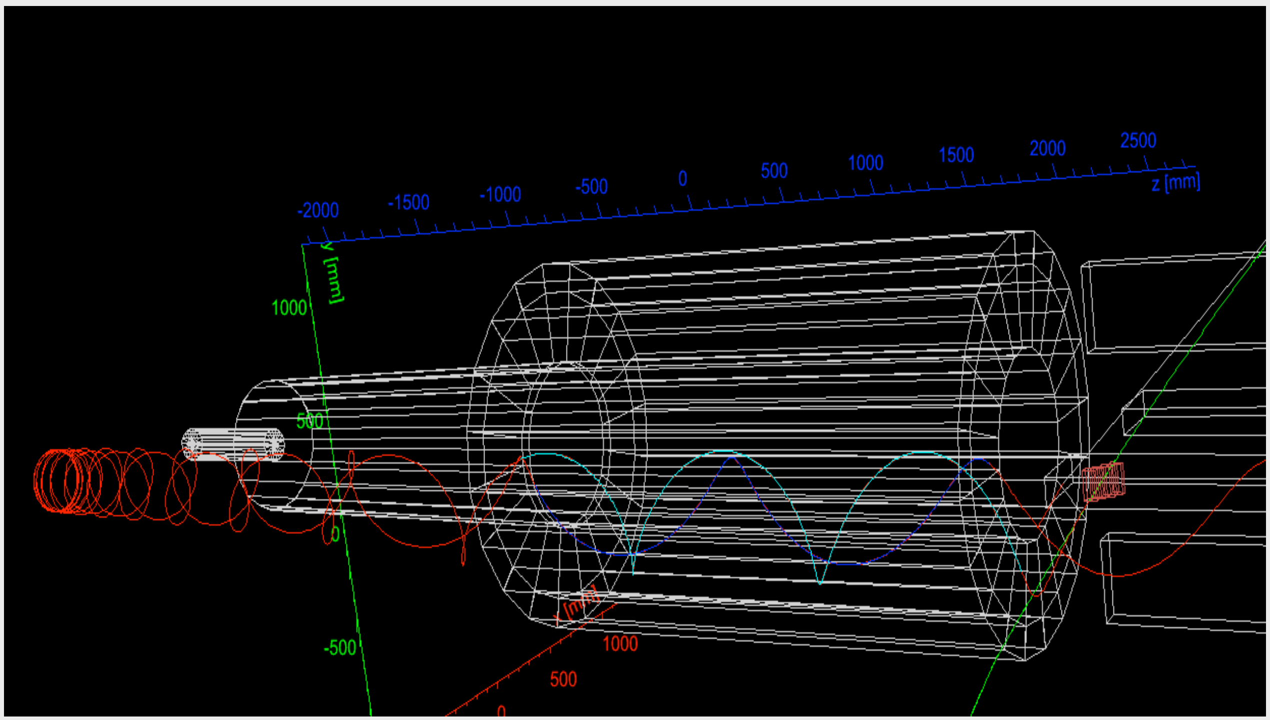
- Precision Surveys
  - X-ray tracker wire positions
    - 50 μm precision
  - Map B-field (2 Gauss goal)
- Calibrate using $\pi^+ \rightarrow e^+ \nu$
  - Requires special detector and beam configuration
  - Under study

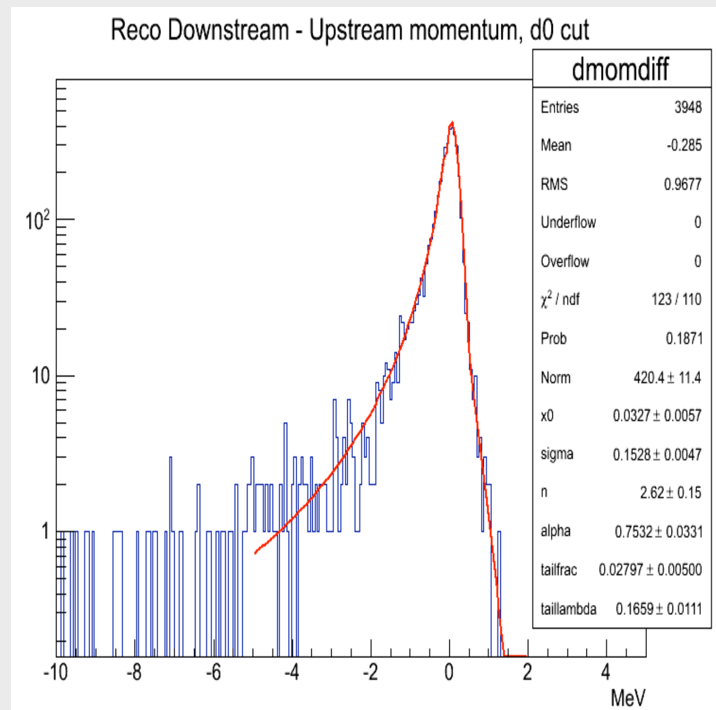
- Fit DIO spectrum
  - Spectrum from theory
  - Resolution from cosmic $e^-$
- Toy MC study: 15 KeV/c statistical resolution possible



# Measure Resolution

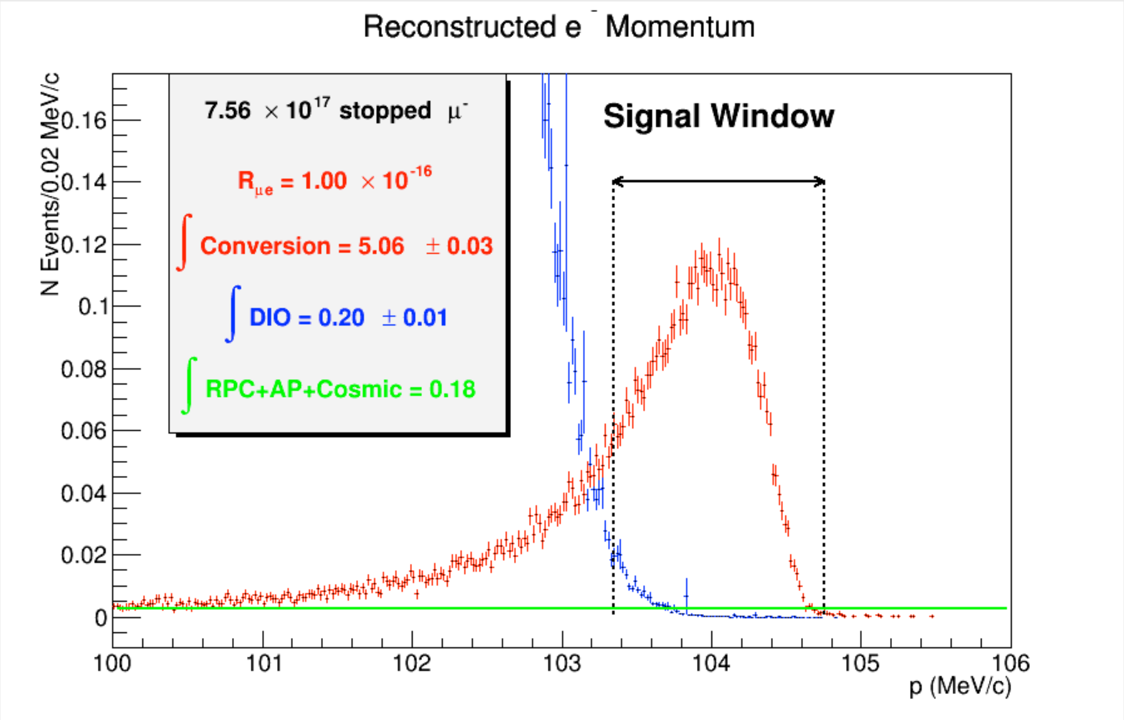
- Don’t have two-body decays and a mass peak
- Cosmic rays hitting the calorimeter can produce $e^-$ that reflect in the upstream gradient field
  - Allows 2 independent measurements of the same particle
- The momentum difference gives the resolution function
  - Also measures the energy loss in passive material



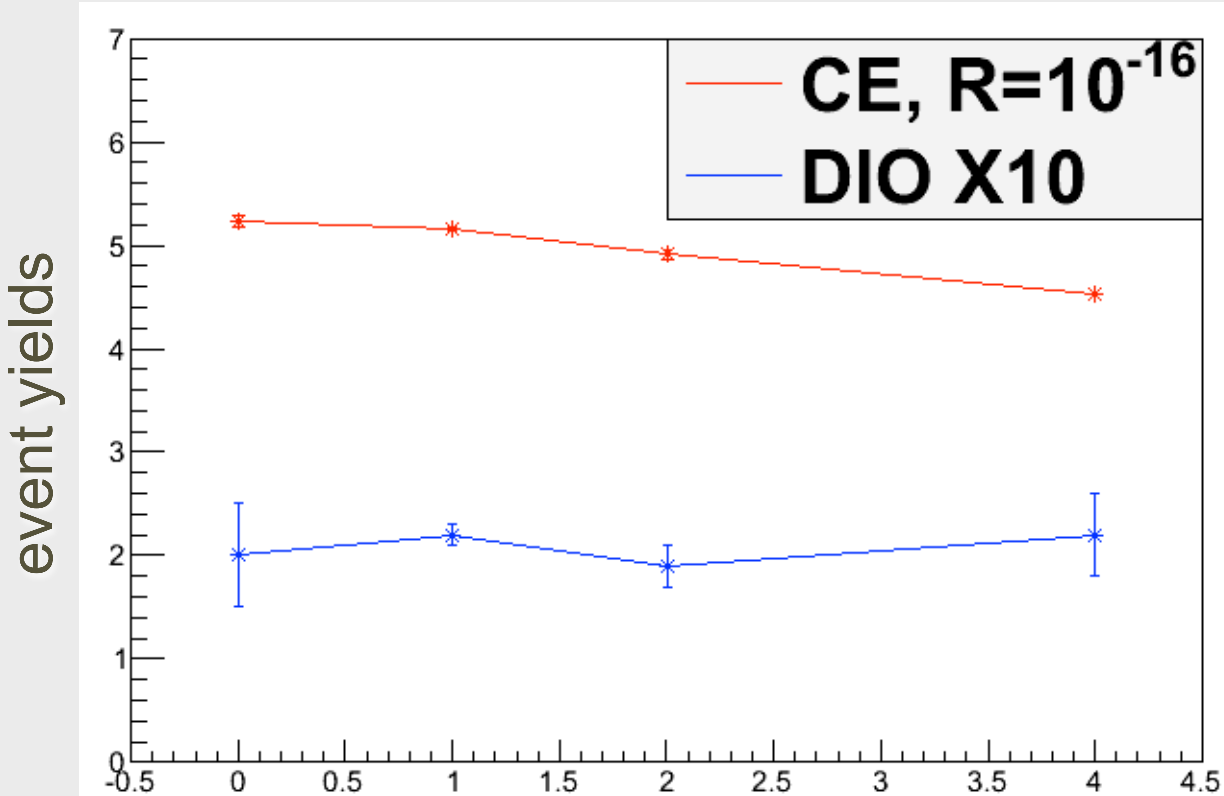
# Current Algorithm

- Full Simulation, Accidental Activity, measured resolutions for 3rd coordinate
- Acceptance 10.8%:
  - time window ~50%, reconstructible tracks ~ 40%




already 25% better than CDR and additional optimizations underway

# Background Sensitivity




Background rate relative to Mu2e nominal (=1)

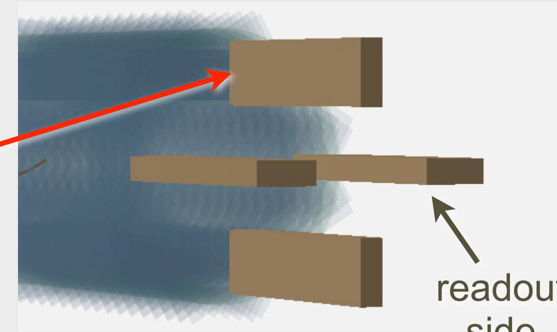
- Momentum resolution unchanged, efficiency reduced by 5% (relative) with 4X nominal background

# Calorimeter

- Timing
- E/p
- Position
- And Particle ID: reject 105 MeV/c muons
  - we're finding (thanks to ability to MC far more with grid technology) very rare backgrounds that calorimeter can reject
- RPC Background Measurements
- New physics measurement

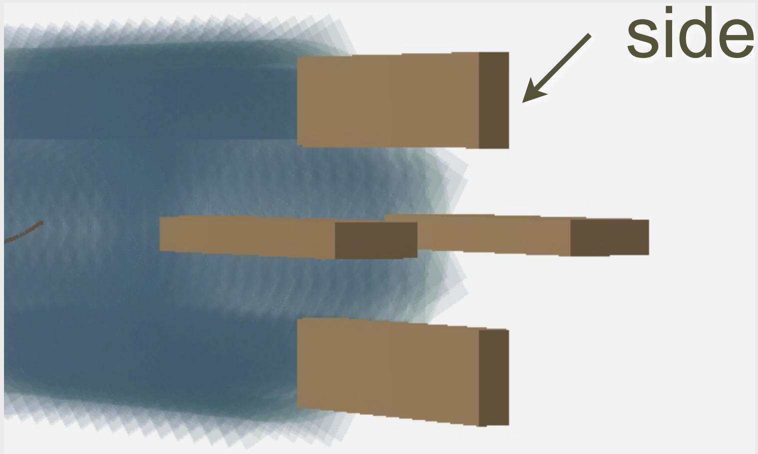
# New Calorimeter Configuration

- Old Configuration Four Vanes
  - not charge symmetric
  - but neutrons from muon capture in the stopping target mostly hit front edge; electrons enter on large rectangle

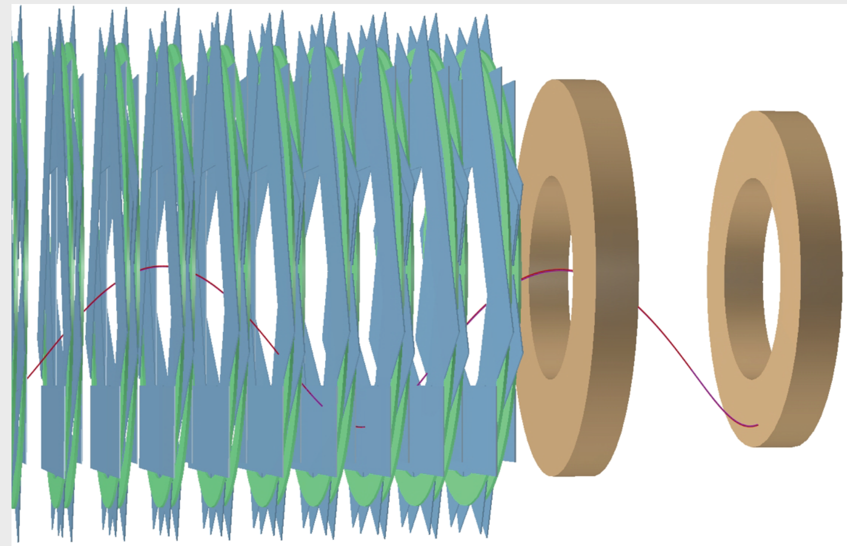



- We want charge symmetry
  - Helps perform unique physics measurement of $\mu^- N \to e^+ N$
  - *the key prompt bkg, RPC, charge-symmetric: as many $e^+$ as $e^-$*
    - can look in the momentum signal box at $e^+$ and since checking opposite charge, experiment is still “blind”

# New Configuration




Two discs are separated by ~1/2 “wavelength”

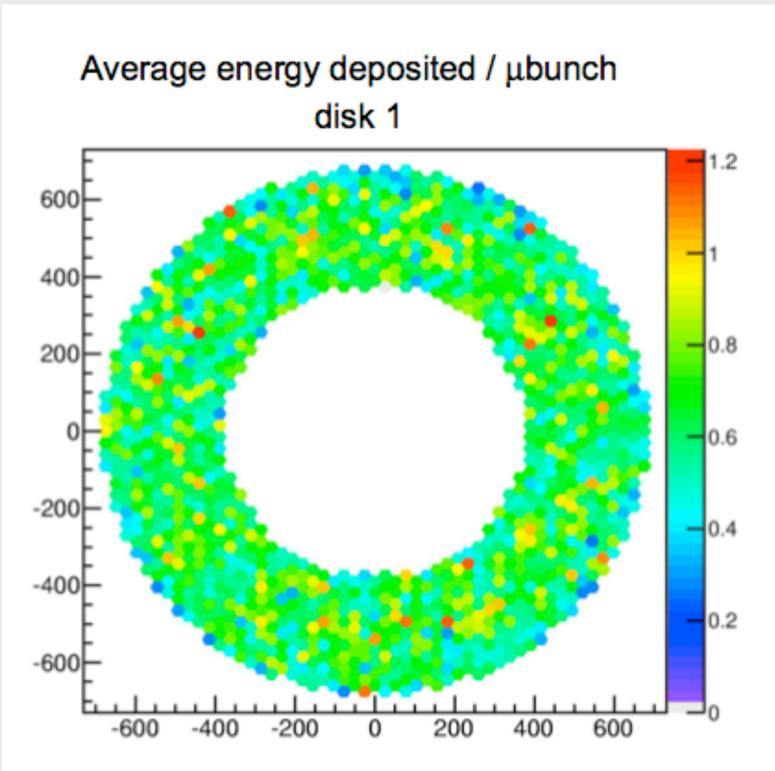


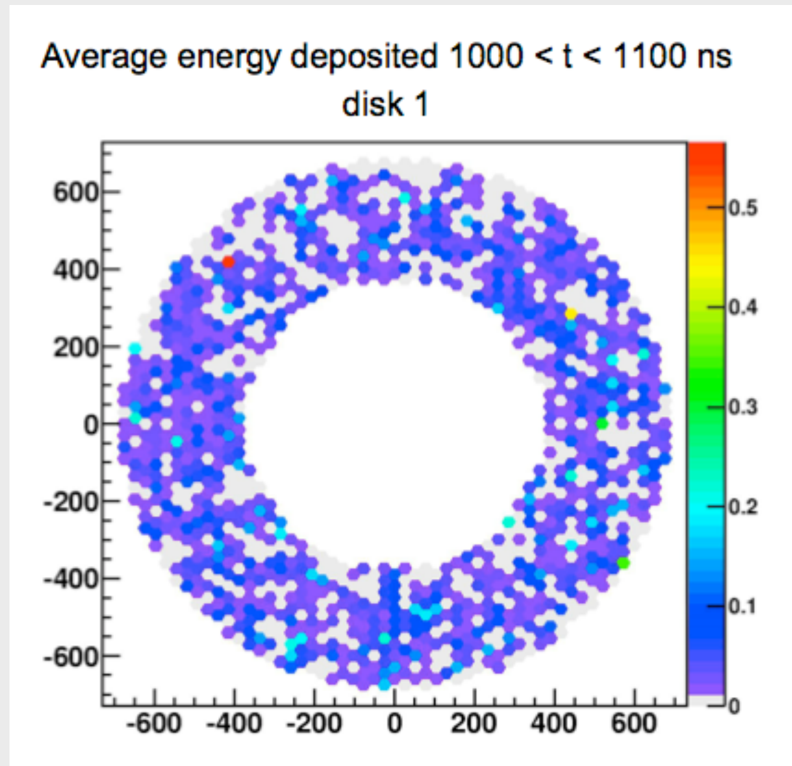
if conversion electron passes through first hole, it can hit second disk

5x5 LYSO array to be tested at Mainz this fall;
Caltech & Frascati are calorimeter team

# Will this Work?

- Calorimeter now face-on to all particles produced from neutrons, photons, etc from muons captured in stopping target
- Using full simulation:

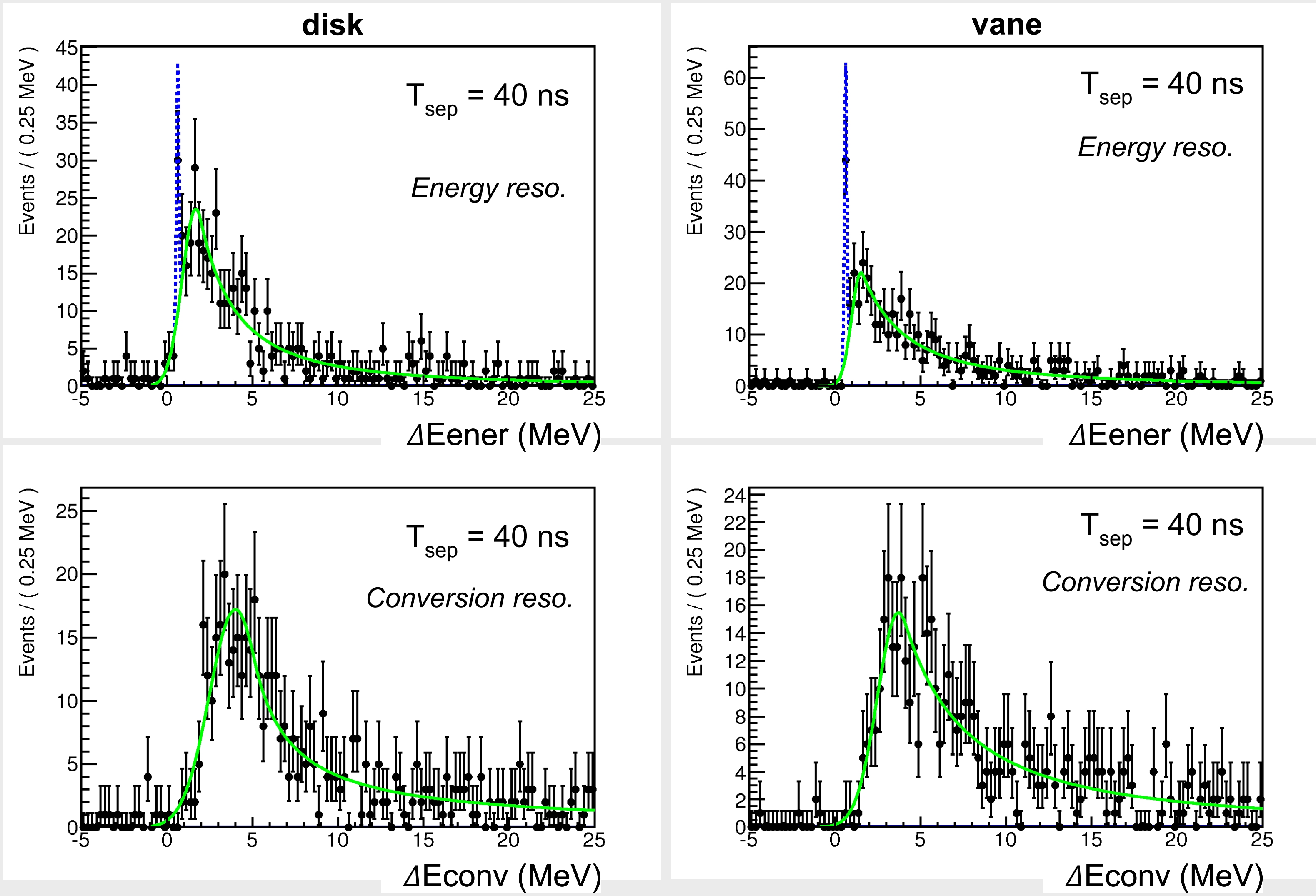



B. Echenard, Caltech

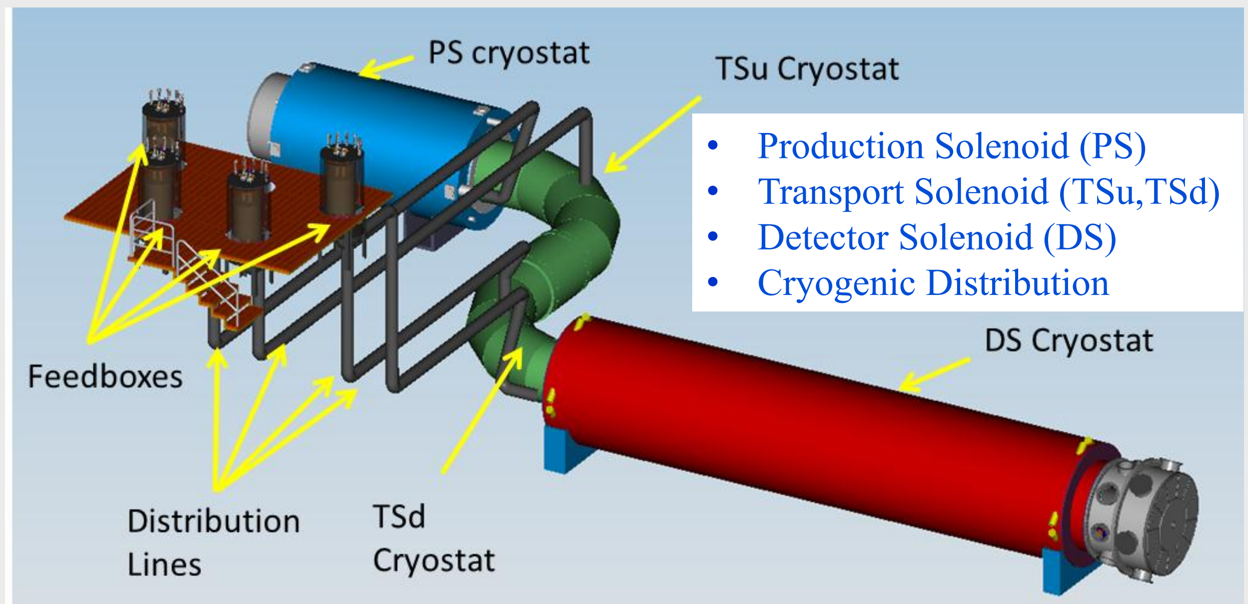
# Yes

## Resolution - Crystal Ball fits



# Outline

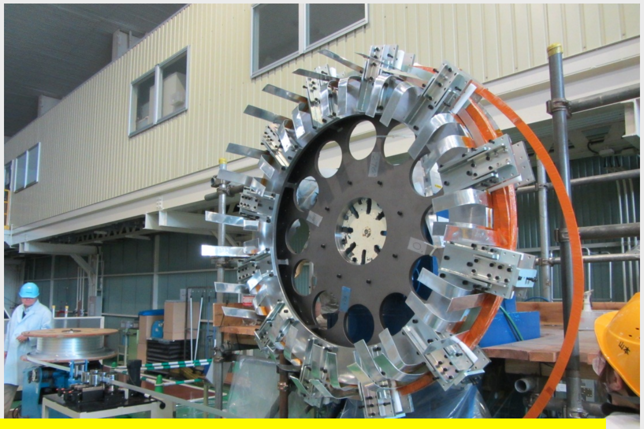
- Physics Case and Review
- Software/Simulation Status
- Experiment Design Updates
- Solenoid Status
- Accelerator Status
- Issues
- Milestones
- Conclusions



# Solenoid Prototypes

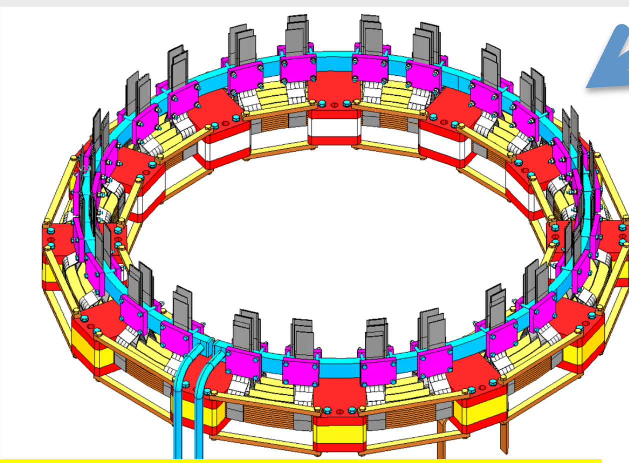
- Ordered:
  - 0.5 km cable for Production and Detector Solenoids
  - 4 km for Transport Solenoid
    - The vendor has made 80 km of TS strand that meets or surpasses all our specifications.
    - They are now making a cable out of that strand (need < 60 for 4 km above, so have spare strand)
  - We have received and are testing the first batch of PS strand.  DS strand will arrive in next couple months.

# Winding Test Coil

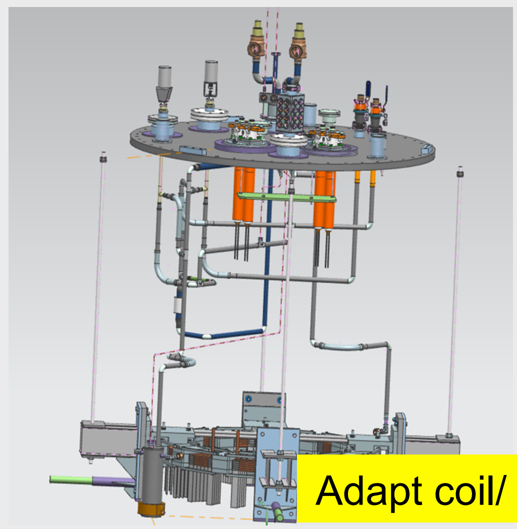


Fabricated at Toshiba 2012

Shipped to Fermilab in December



Indirect Cooling at Fermilab



Adapt coil/ modify test cryostat

expect test late summer/ early fall 2013

# TS Prototype

- Module Prototype:
  - fabrication, splices, cooling, training and stability, axial forces, magnetic measurement

- FNAL-INFN collaboration planned
  - FNAL: cable and supporting shell, tests
  - INFN: coil fabrication and integration in industry
- Get cable in fall, start winding!

# Outline

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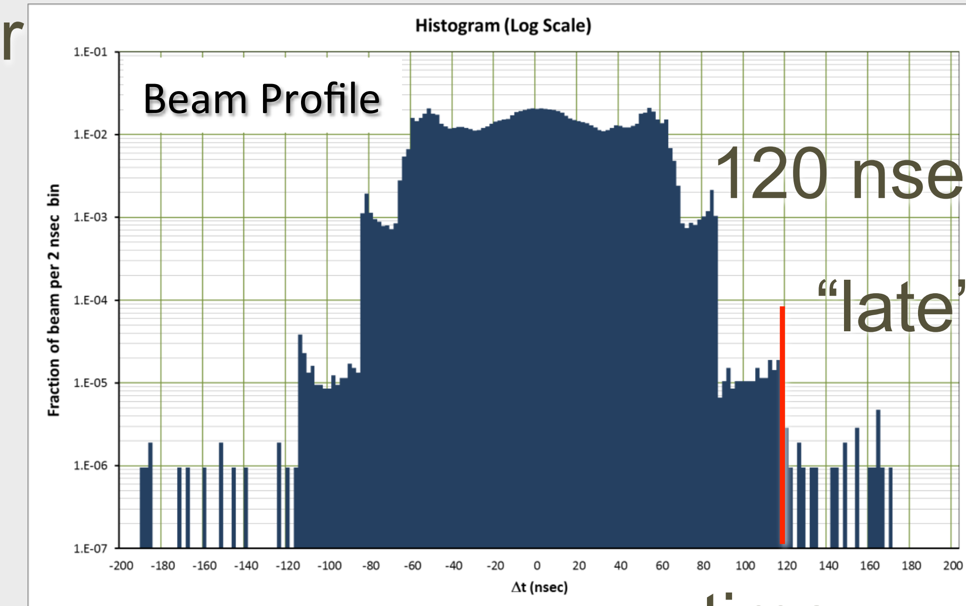
# Beam Modeling

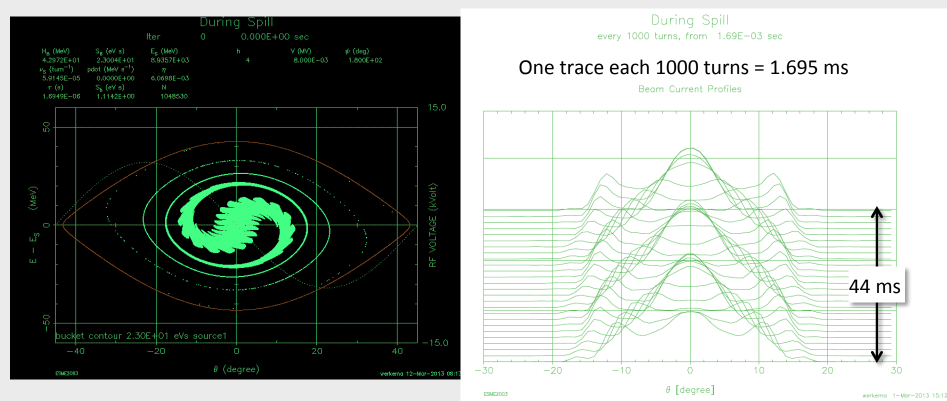
- "Late" Protons have a higher probability of producing pions that get into measurement period and produce RPC background
- Protons outside around ± 120 nsec ~ 3e-5, extinction dipole ~ $10^{-6}$ : < 3e-11 overall
- Need $10^{-10}$ (can adjust timing of extinction dipole to fine-tune)




120 nsec

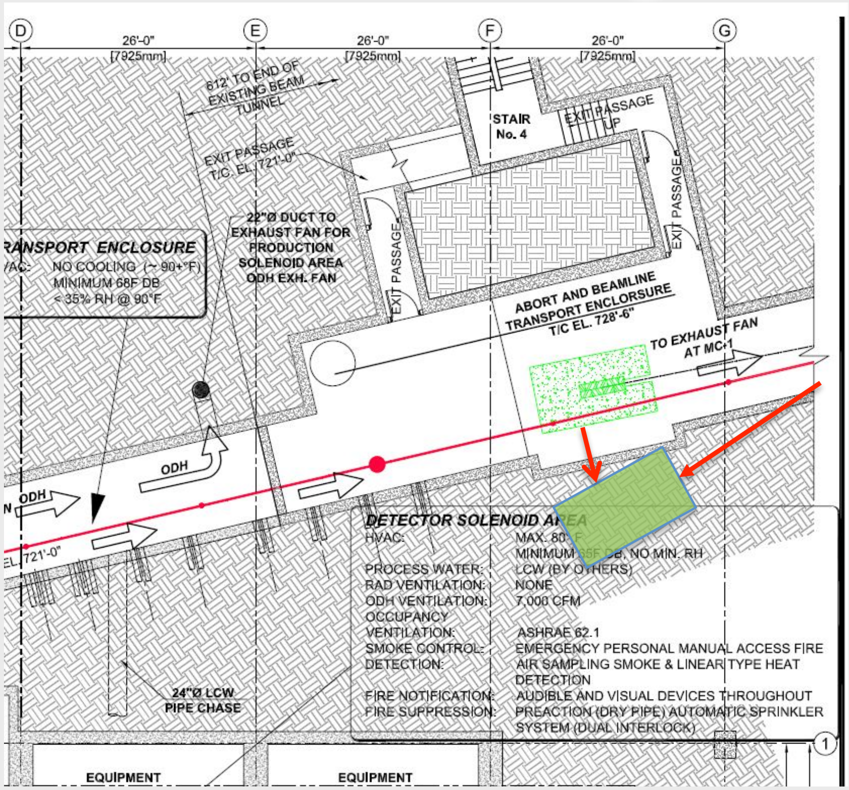
"late"

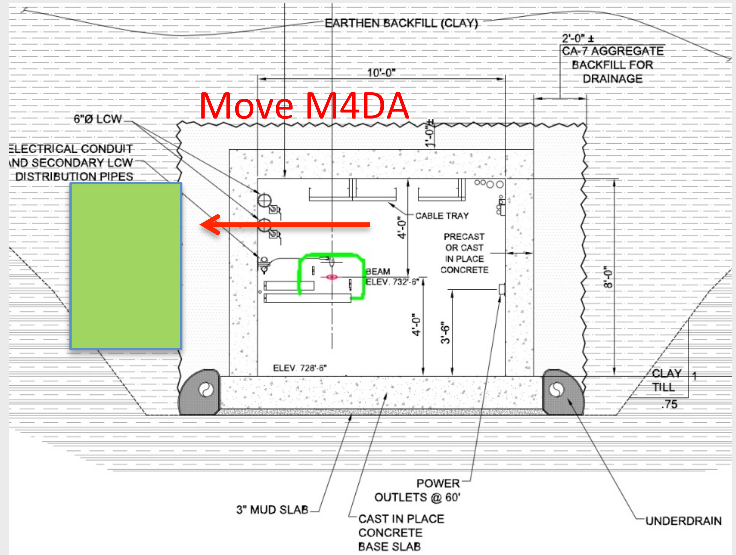
time→




time dependence of spill

# Diagnostic Dump




- Measure extinction before data-taking: check and diagnose here during data-taking if needed
- Can directly measure entire beam
    - which is destructive but fast

# Outline

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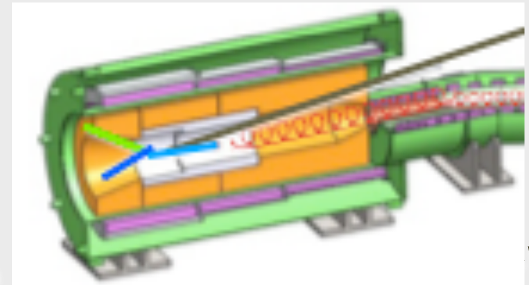
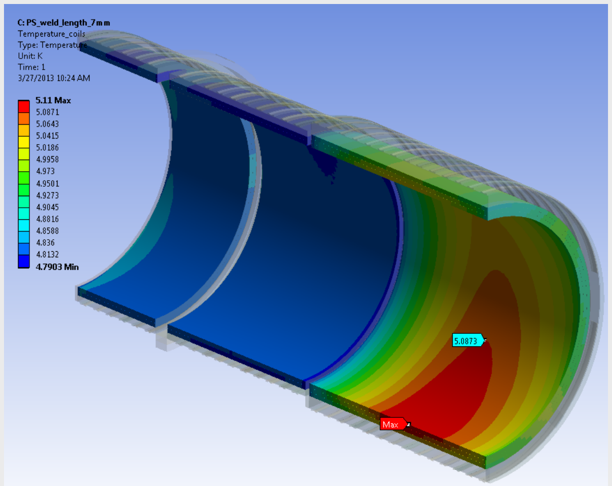
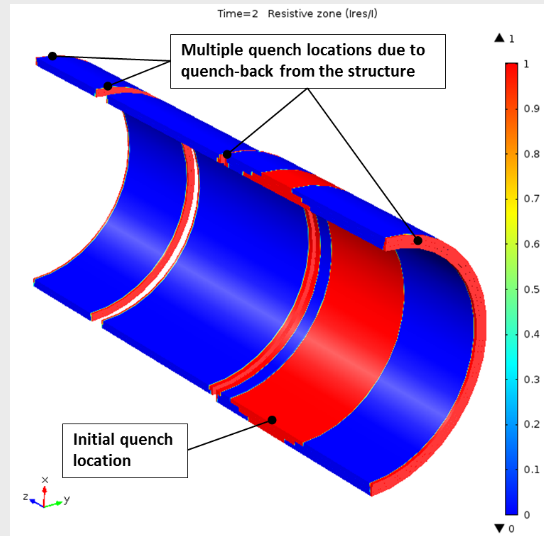
# Issues



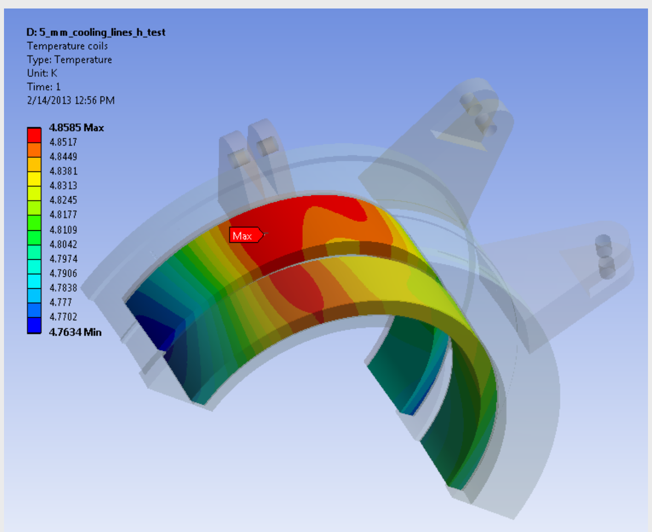
- Heat and Radiation Shield
  - Still checking and tuning the design of an 8 kW beam targeted inside a superconducting solenoid
  - long term issues far beyond Mu2e (upgrades, neutrino factories, muon colliders...)
- *Neutrons*
  - *our primary production target – 8 GeV collisions– and our muon beam denominator, all muon captures, make neutrons*

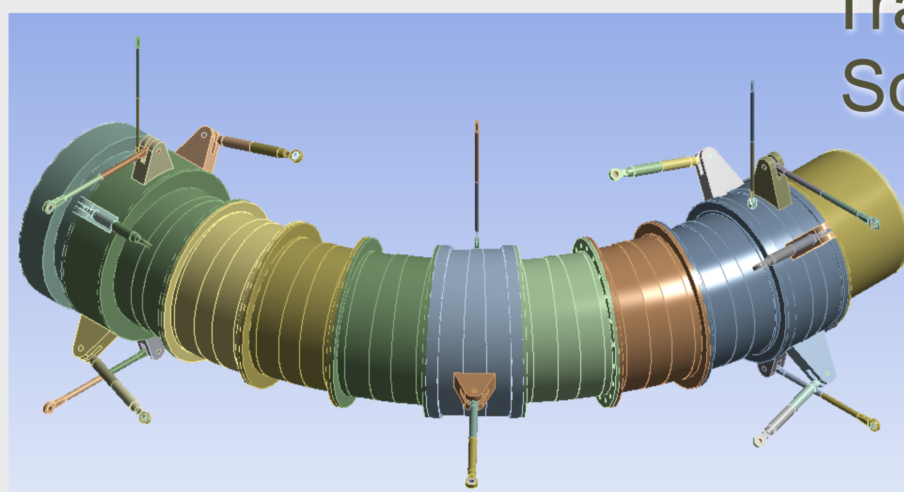
# Thermal and Quench Analyses




Production Solenoid

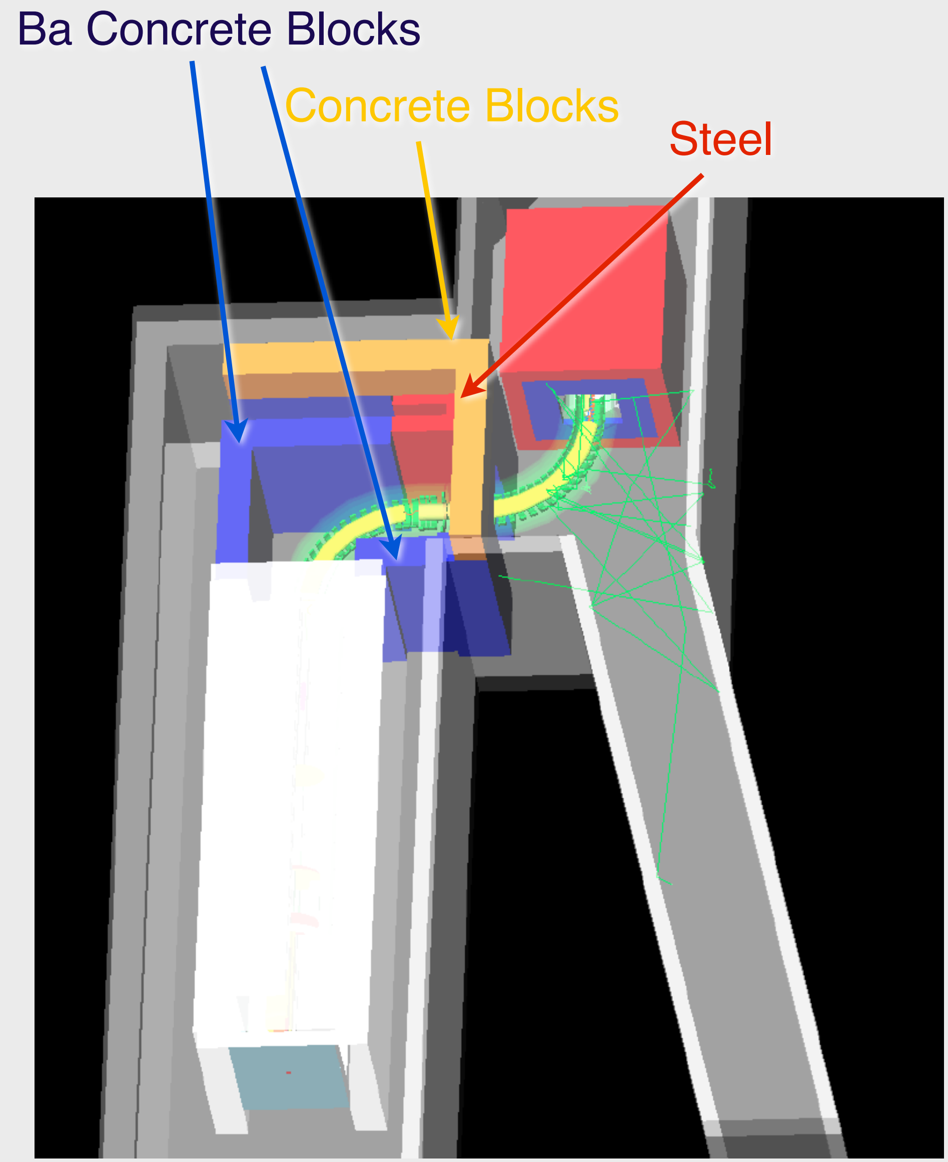


Transport Solenoid

# Neutron Activity

- Neutrons are produced by several sources in Mu2e
  - Primary target, collimators, μ stopping target, beamstop, ...
  - and make many photons
- Neutrons affect the detectors
  - Radiation damage to SIPMs (esp. CRV)
  - Fake hits in the tracker and calorimeter
- Fake coincidences in CRV
  - Reduces conversion efficiency
- Neutron mitigation:
  - Shield CRV with concrete and steel
  - Use fiber readout to move SIPMs out of high-flux regions
- Optimization still in progress



# Outline

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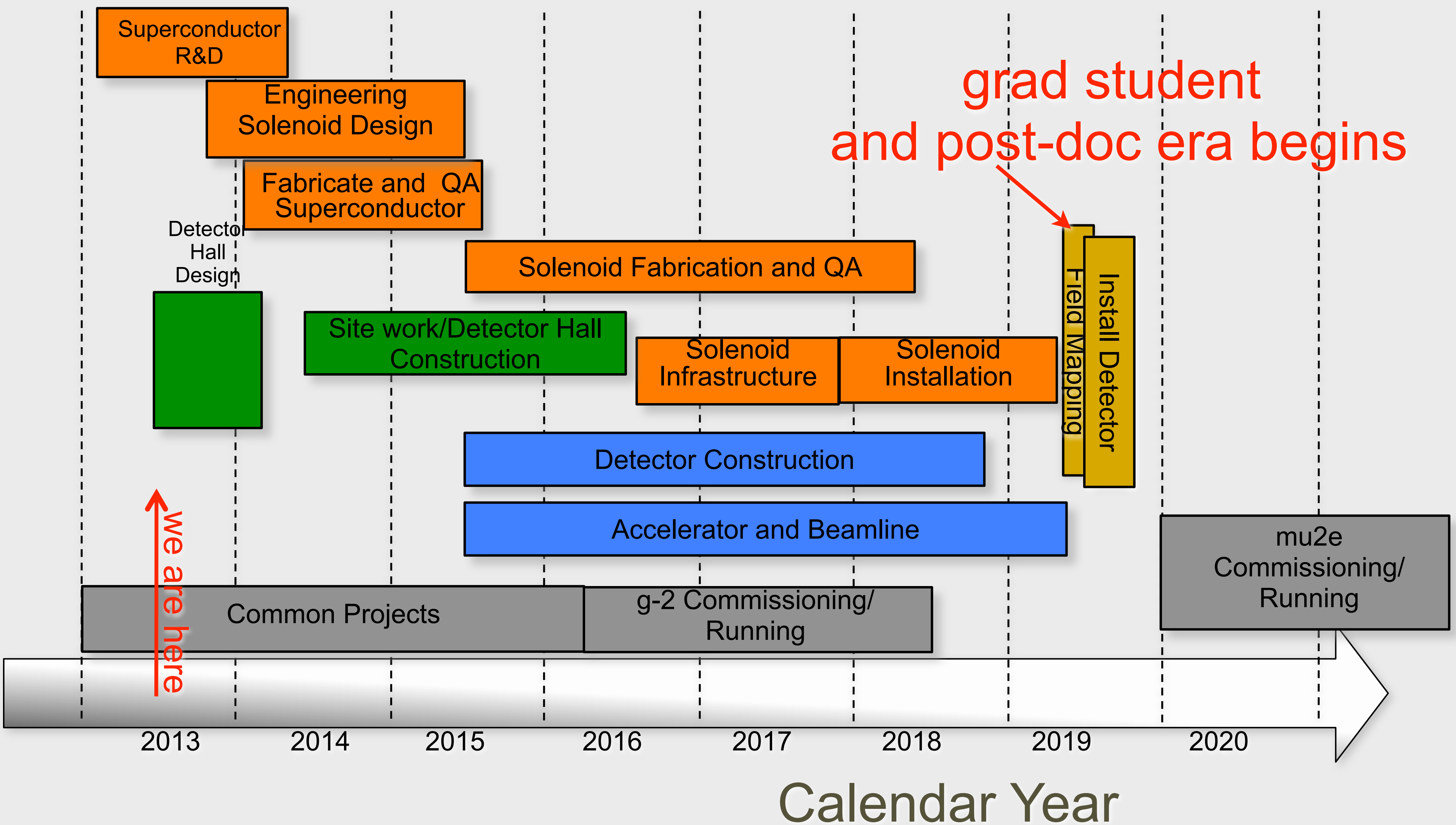
# Backgrounds

| Source | Events | Comment |
|---|---|---|
| Anti-proton capture | $0.1 \pm 0.06$ | Assumes $10^{-10}$ extinction |
| Radiative $\pi^-$ capture | $0.04 \pm 0.02$ | |
| Beam electrons | $0.001 \pm 0.001$ | |
| Decay in Orbit | $0.2 \pm 0.06$ | |
| Cosmic ray induced | $0.025 \pm 0.025$ | Assumes $10^{-4}$ inefficiency |
| $\mu$ decay in flight | $0.01 \pm 0.005$ | With $e^-$ scatter in target |
| Total | $0.4 \pm 0.1$ | |

$R_{\mu e}$ (SES) $= 2 \times 10^{-17}$ $R_{\mu e}$(90% CL) $= 6 \times 10^{-17}$

# Mu2e Schedule



# Conclusions

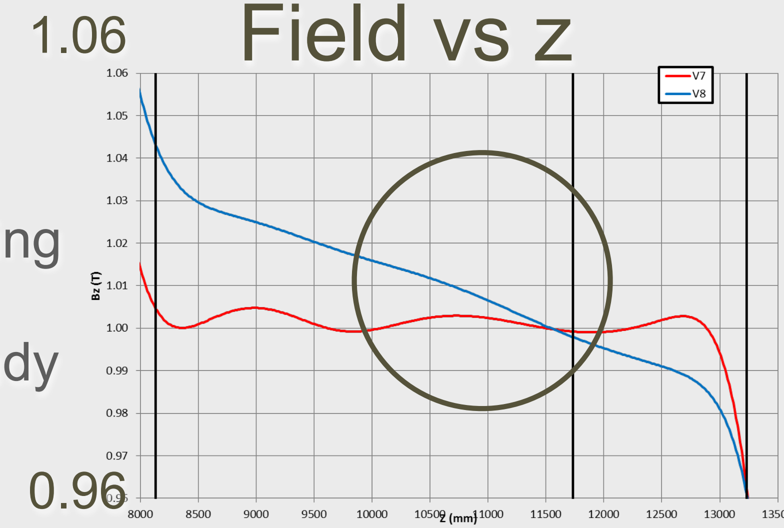
- Mu2e is still important; if anything, more so than when proposed
- Simulations and Experiment Design have significantly advanced over the last six months
  - a lot I didn't have time to show is underway
- Active Prototyping Program
- A few issues, but no show-stoppers.
  - Lab is putting resources into the problems
- Will Be Moving from Design to Construction over next year

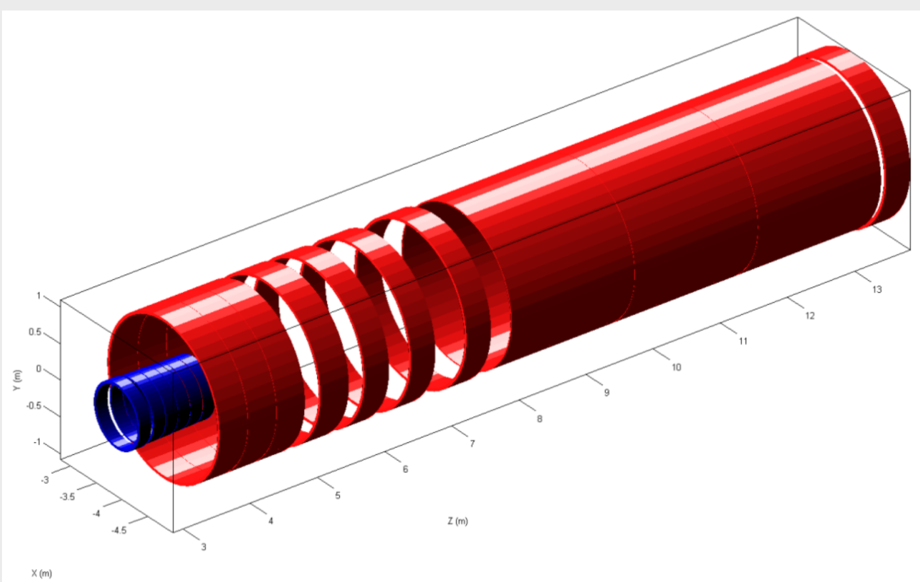
# Backups

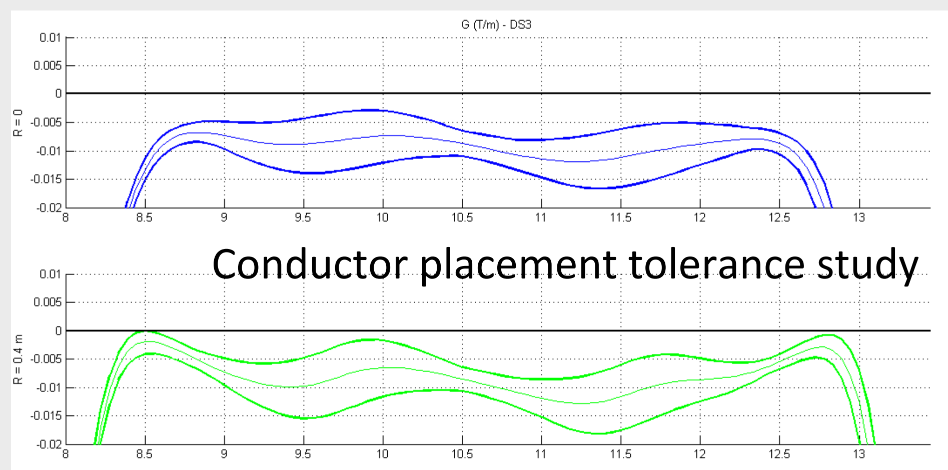
# Detector Solenoid

- Optimizing field design to reduce potential backgrounds
    - introduced small gradient to eliminate trapping
- Preliminary Conductor placement tolerance study completed
- Stray field analysis in progress

Field vs z

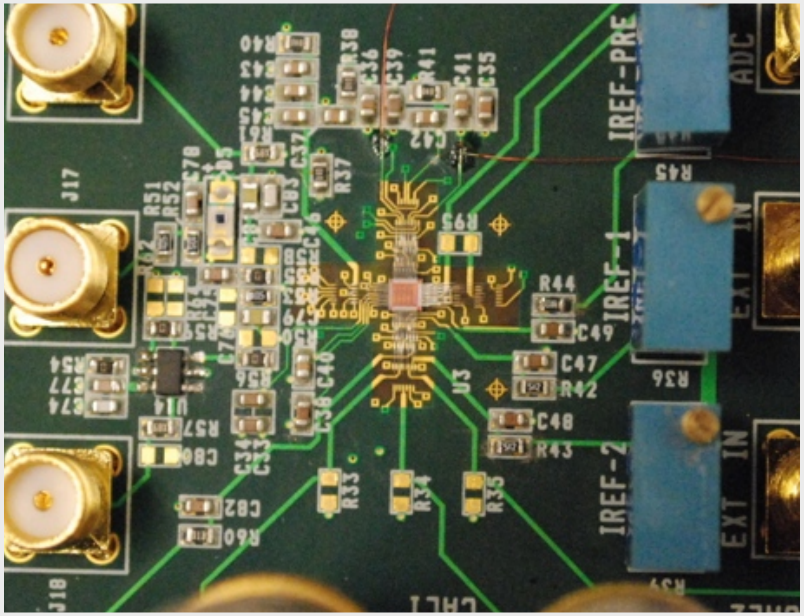


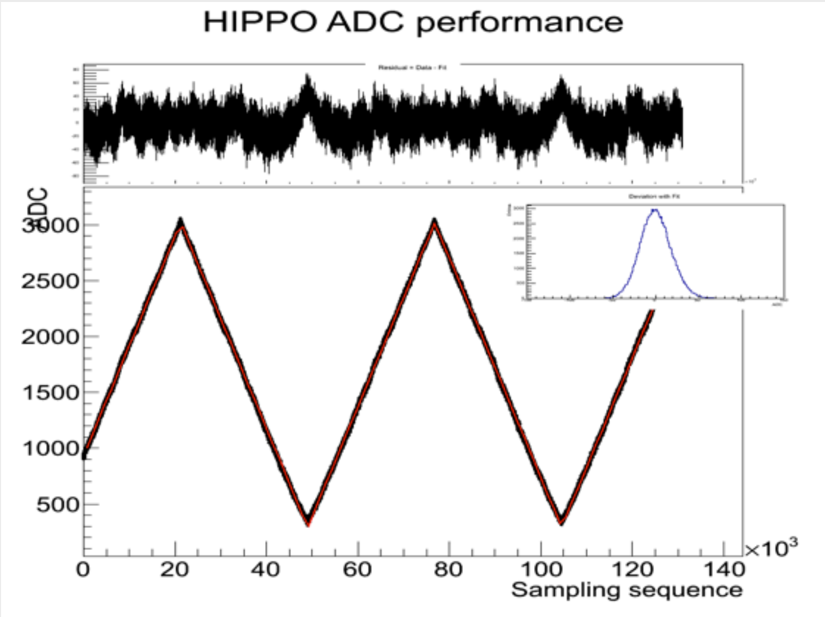



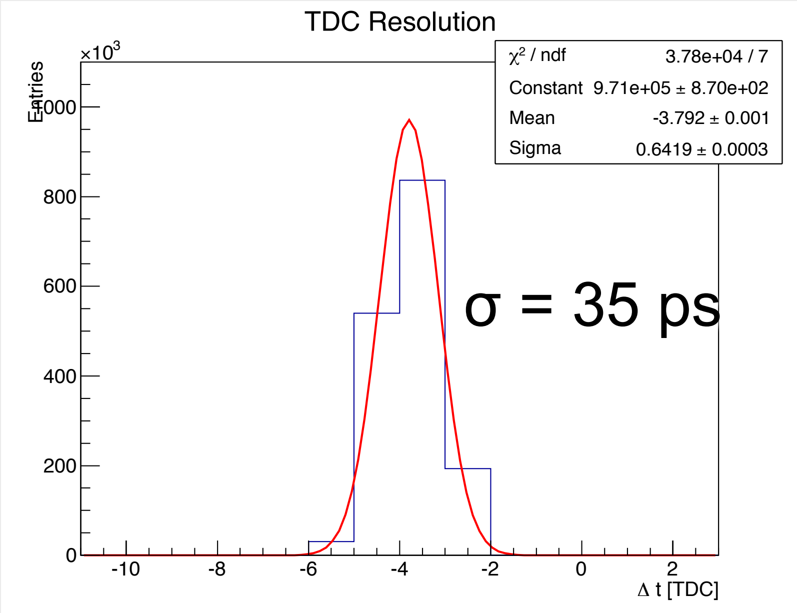



# Tracker ASIC

- 65nm process
- Oscillator-ring dual 16-bit TDC
- 10 (12) bit ADC
- 4-channel prototype

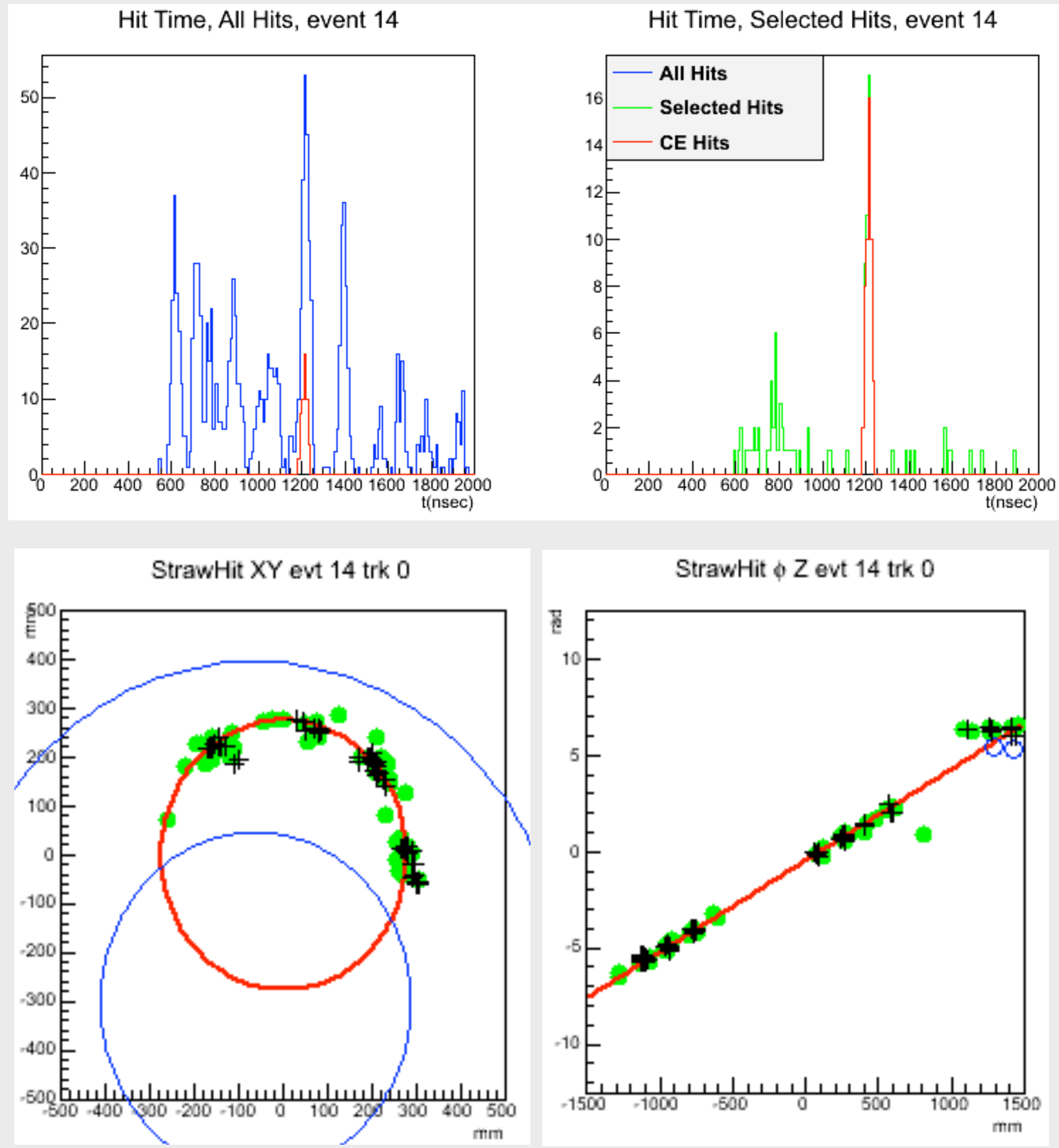




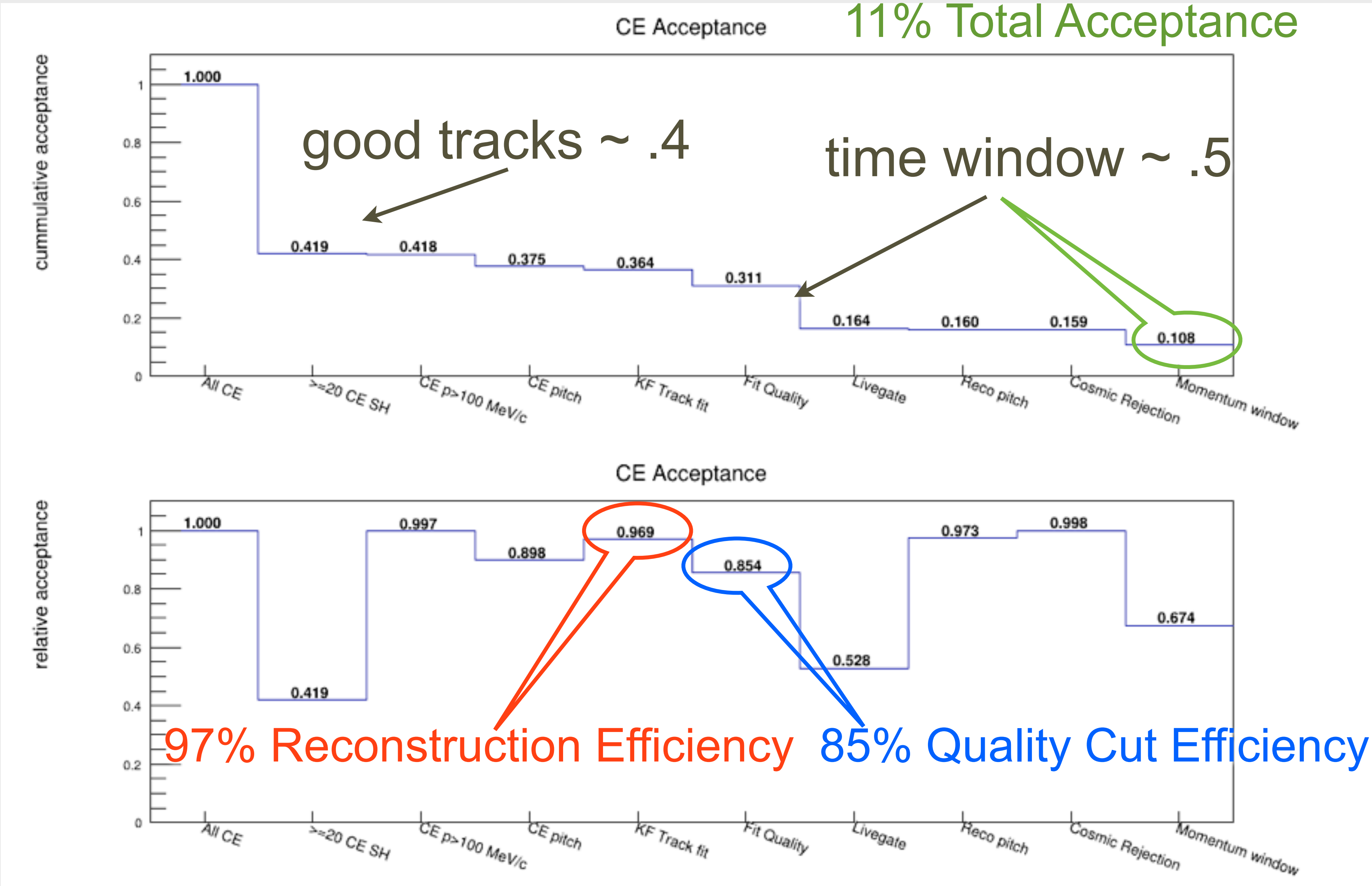



# Track Finding and Fitting

- Remove hits from low-energy electrons
- Remove hits with large energy deposits (protons)
- Select hits which peak in time
- Fit in sequence:
  - Robust Helix
  - Least-squares
  - Kalman Filter

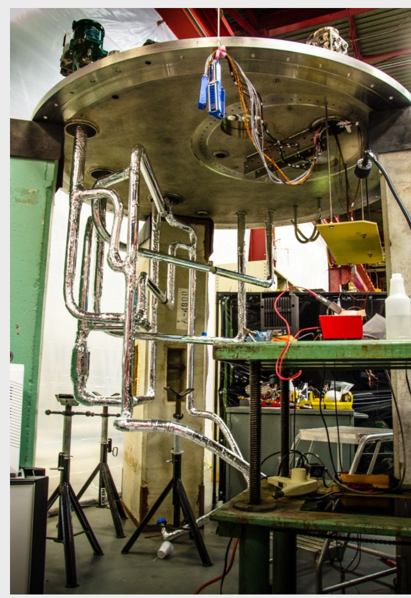


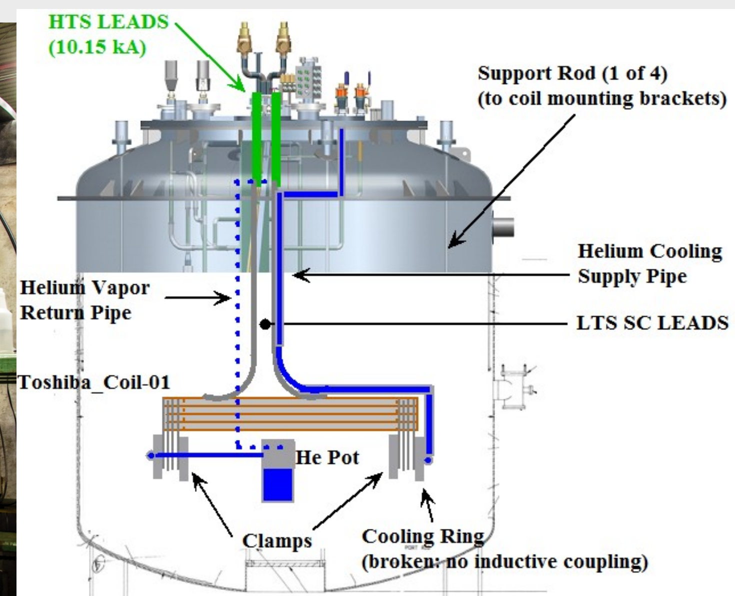
# Reconstruction Efficiency



# Test Facility Upgrades

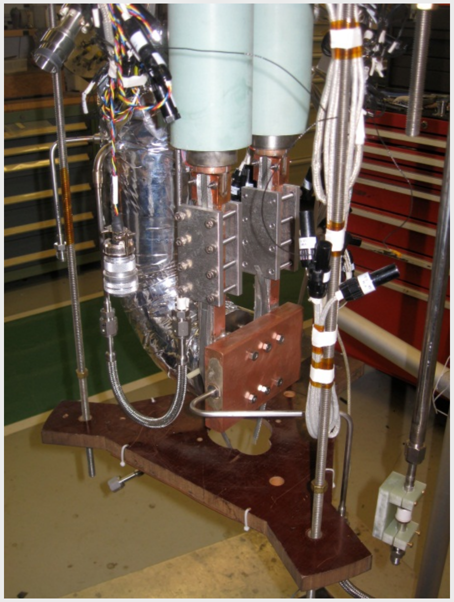
- New Facility for large, indirectly cooled solenoids (MICE and Mu2e)
- And improvements for higher current in Mu2e
- Will Test Toshiba Coil and TS prototype



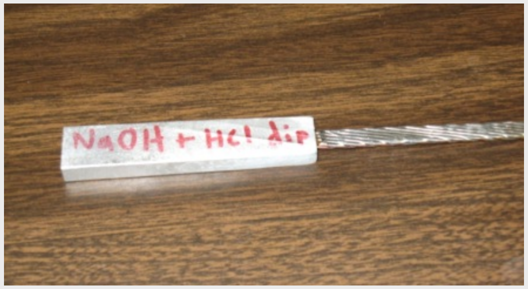


# Splices and Leads

- Splice tests will be performed in Magnet Test Facility
- Integrate with Test Winding Coil: welded joints, remove Al for Cu-Cu joint to connect to power leads
- Investigate radiological technique (learn from CERN)

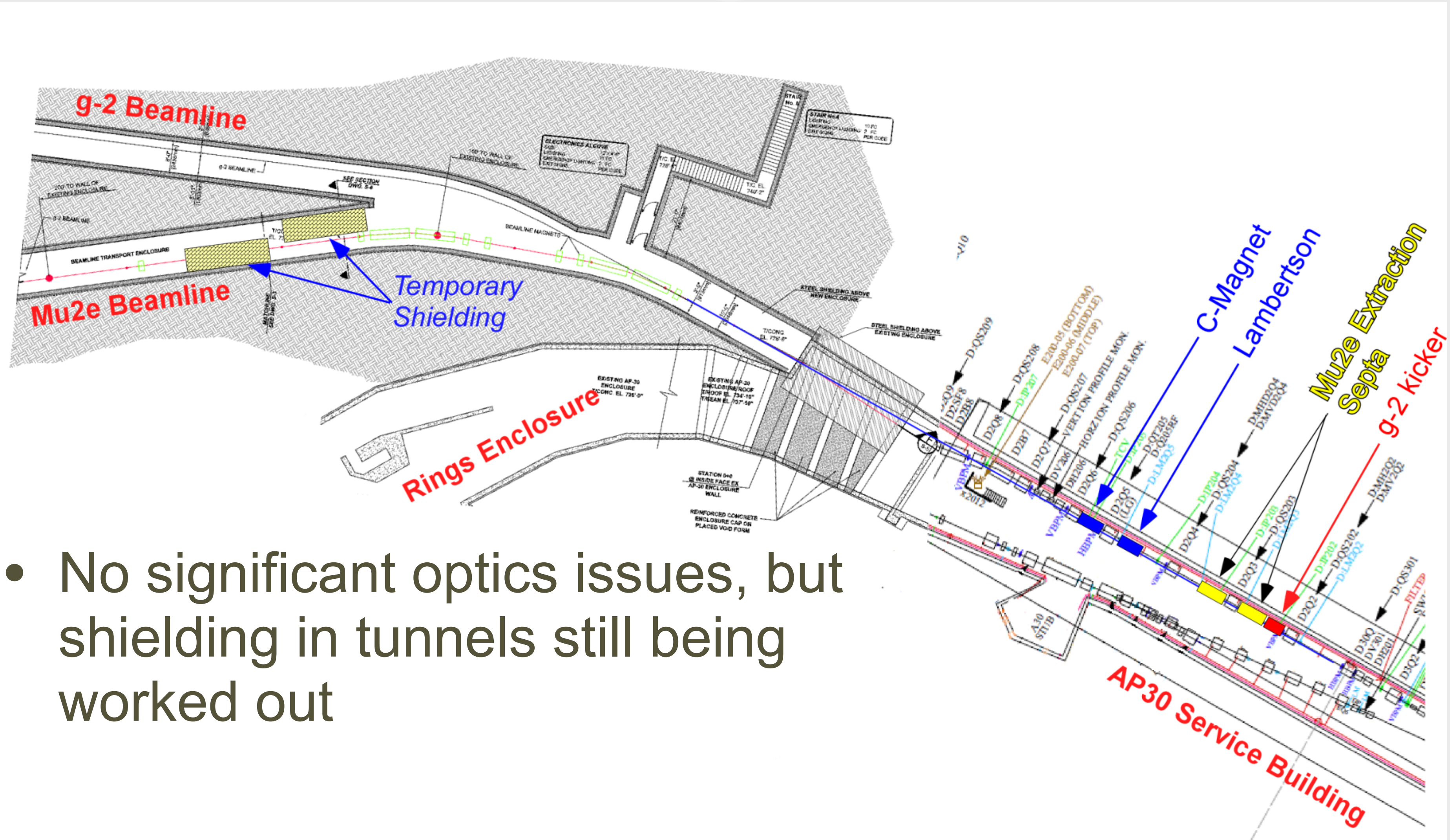


TeV HTS leads in MTF test area



splice sample with AL cladding chemically etched away

# Beamline and Integration With g-2




- No significant optics issues, but shielding in tunnels still being worked out

# Accelerator-I

- Heat and Radiation Shield (HRS to protect superconducting coils) Design solution is near: brass plus water.

- Production target design: Radiation-cooled vs water-cooled:

  - Rad-cooled easier to support and to service with remote handling, but higher vacuum required ($10^{-6}$ torr vs $10^{-1}$ torr)

  - If $10^{-6}$ torr not achieved, a rad-cooled tungsten target may erode from interaction with H2O. Possible solution: iridium-coated tungsten. Tests underway at RAL

# Accelerator-II

- Other systems progressing well (much off-project or g-2)
- Design work on the extraction septum, RF knockout kicker, spill monitor, and magnet systems is on track. Work on resonant extraction beam transport and loss models is very advanced
- Mu2e Beamline: Optics design for 80% of line is complete, sufficient to fix the position of the proton target

# AlCap Measurement

- Mu2e/COMET Collaboration
  - U. Wash, BU, Houston, Lecce, PNNL, ANL
- Muons captured in stopping target produce n,p, $\gamma$
  - fluxes not well known
  - Use stopped muon beam to measure fluxes for Al, Si, Ti
- Low Energy negative muon beam at PSI
  - one month scheduled in Dec 2013, possibly more in Spring 2014

# Review Schedule

- Received CD1 June 2012
- Receive CD3a December-January 2014
  - authorizes purchase of long lead time item: superconductor for solenoids
- Currently preparing for coincident CD2/CD3 review spring-summer 2014
- CD2: Cost, schedule, scope, baseline, TDR
- CD3: Final or near-final design
  - Receive CD2/CD3 Late FY 2014
- Break ground on building Oct 2014